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REGIONAL STUDY OF ROCK DRAINS IN SURFACE COAL MINES IN CANADA - PHASE I

FINAL REPORT BY:

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EXECUTIVE SUMMARY

Placement of mine waste rock in valleys has proven to be an economical method of waste disposal. The primary engineering and environmental concern associated with this method of disposal is the impact that the fill will exercise on the stream occupying the valley floor.

Piteau Engineering Ltd. was commissioned by Supply and Services Canada (DSS) to review the current approaches being followed by operating coal mines in the design, construction, and performance monitoring of rock drains utilized for waste dumps and road embankments located in valley floors. Information pertaining to the design and performance of 9 rock drain installations at 6 mine locations in Alberta, the Yukon Territories and British Columbia were researched and pertinent information is presented herein.

Principal design concerns are the peak flow rate anticipated for design, the flow capacity of the rock drain, the strength and durability of the drain construction material, the short and long term stability of the rock drain and overlying waste fill, and the impact the rock drain will have on stream flow and quality.

Acceptable methods for predicting the design flow rate, generally defined as the 1 in 200 year mean daily flow, include the frequency analysis of flood discharge, the regional analysis of measured discharge, the index flood, the rational method, and rainfall - runoff models. Of the above, the frequency analysis of flood discharge is generally preferred.

The flow capacity of the rock fill depends on a number of factors, the most important being the hydraulic conductivity of the rock fill and its continuity. The upper and lower bounds of the flow capacity of the rock drain should be estimated. The minimum capacity may be applicable in rock fills that are prone to degradation and may be used to determine the potential for ponding behind the rock fill. The maximum potential flow will occur if the rock drain consists entirely of coarse segregated rock fill.

Preferable construction materials include sandstone and hard siltstone for coal mines and igneous rock and hard metamorphic rock for metal mines. Preferred rock properties are as follows:

Los Angeles abrasion	40%
Uniaxial compressive strength	50 MPa
Slake durability	90%
Fines content	5%

At locations where the the run of mine waste rock is not sufficiently strong or durable to be used in the rock fill, selected sound rock must be used for construction of the rock drain. Experience indicates that dumping the rock fill from a height of over 20 metres is desirable to promote segregation of the rock, whereby the base rock drain comprises stronger coarser material, preferred for rock drain construction. Where the amount of select rock is limited, an underdrain may be placed at the bottom of the dump in advance of dump construction.

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Design, construction and performance monitoring information was collected for the following mining operations:

1.	Smoky River Coal Ltd.	- No. 12 Mine Access Road Creek Crossing
2.	Crows Nest Resources Ltd.	- Line Creek Rock Drain
		- West Line Creek Rock Drain
		- No Name Creek Rock Drain
3.	Byron Creek Collieries	- East Waste Dump
4.	Westar Mining Ltd.	- Greenhills Operations
		- Porter Creek Waste Dump
		- Cataract Creek Waste Dump
5.	Bullmoose Coal Mine	- Y Creek Rock Drain
6.	Gregg River Resources Ltd.	- Berry's Creek Rock Drain

The performances of other selected rock drain case histories are also summarized. Long term performance of the rock drain is the principal operating concern, which can be assessed by implementing a structure monitoring program. Typically, this would include measurement of flow in and out of the rock drain, dye tests to measure flow velocity, and water quality and sediment monitoring upstream and downstream of the drain. Monitoring of slope movement may be implemented if the downslope stability of the drain and fill is of concern.

To date, the operation and monitoring of the rock drains has been satisfactory. The report concludes that the construction of flow-through rock drains is generally feasible and may be accomplished without major impacts on the stream flow and quality.

A rational design methodology is presented in the report; however, refinements will likely be required as monitoring and operating experience becomes available from current and future applications. This should be addressed, in detail, in a subsequent study phase.

RESUME

Le dépôt de déchets de roches minières dans des vallées s'est avéré une méthode économique d'évacuation des déchets. Le premier problème dans les domaines de l'environnement et de l'ingénierie que pose cette méthode d'évacuation est l'impact du remblayage sur la rivière coulant au fonds plat de la vallée.

Approvisionnement et Services Canada a chargé Piteau Engineering Ltd. d'étudier les dernières méthodes de conception, de construction et de contrôle des résultats des drains à pierres sèches utilisés pour les remblayages situés aux fonds de vallées. En outre, nous présenteons dans ce résumé, les résultats de nos recherches sur la conception et la performance de 9 systèmes de drains situés dans six mines en Alberta, dans le Yukon et en Colombie-Britannique.

Au plan de la conception, les principaux problèmes recontrés sont le débit maximal prévu, la capacité de débit du drain, La solidité et la durabilité des matériaux de construction du drain, la stabilité à court et à long terme du drain et due remblayage de couverture et l'impact du drain sur le débit et la qualité de la reivière.

Les méthodes acceptées pur prévoir le débit, défini généralement à 1 dans 200 par an d'écoulement quotidien moyen, comprennent l'analyse de la fréquence de la décharge d'inondation, l'analyse régionale de la décharge mesurée, l'indice d'inondation, la méthode rationnelle et les modèles de précipitation et de ruissellement. Il est préférable de choisir l'analyse de la fréquence.

La capacité de'écoulement du remblayage dépend de plusieurs facteurs, surtout de sa conductivité hydraulique et de sa continuité. Les limites maximales et minimales de la capacité d'écoulement du drain devraient être évaluées. La capacité minimale se trouve dans les remblayages sujets à la dégradation et peut être utilisée pour déterminer la possibilité de formation d'étangs derrière le remblayage. La capacité maximale d'écoulement apparaît dans les remblayages à grosses roches.

Une évaluation des effets environnementaux en aval est menée par l'échantillonnage de la décharge du remblayage. Les sédiments et les décharges composées d'azote sont généralement contrôlés. Dans les cas où le volume de la décharge dépasse les limites fixées par la réglementation, les étangs de sédimentation ou l'eau traitée devraient être faits en aval.

Il est préférable d'utiliser comme matériaux de construction le grès et l'aleurolite dure pour les houillères et les roches métamorphique dures pour les mines métalliques. Les propriétés de roches que l'on préfère sont:

.../2

Los Angeles abrasion	40%
Résistance à l'écrasement uniaxe	50Mpa
Durabilité	90%
Teneur en fines	5%

Dans les lieux où le remblayage n'est pas suffisamment solide ou durable, il faudra choisir des roches adéquates à la construction de drain à pierres sèches. L'expérience a montré que la ségrégation des roches est facilement obtenue en laissant tomber d'une hauteur de plus de 20 mètres le remblayage, ainsi le drain de base à pierres sèches a un matériau plus solide à ségrégation grossière plus convenable à la construction du drain.

La performance à long terme du drain à pierres sèches est le principal souci, cette perforamnce peut être évaluée en contrôlant la structure. Cela inclus généralement un mesurage de l'écoulement entrant et sortant du drain, des essais de colorants afin d'établir la vitesse d'écoulement, la qualité de l'eau et le contrôle des sédiments en aval du drain. Le contrôl du mouvement de pente peut être fait si la stabilité du drain et du remblayage pose un problème.

Des renseignements relatifs à la conception, la construction et au contrôl de la performance des exploitations minières suivantes ont été recueillis:

1.	Smoky River Coal	Accès au ruisseau de la mine No. 12
2.	Crows Nest Resources	Drain du ruisseau Line
		Drain du ruisseau West Line
		Drain du ruisseau No Name
3.	Byron Creek Collieries	Remblayage Est
4.	Westar Mining Ltd.	Opérations Greehnills
		Remblayage ruisseau Porter
		Remblayage ruisseau Cataracte
5.	Bullmoose Coal Mine	Drain du ruisseau Y
6.	Gregg River Resources Ltd.	Drain du ruisseau Berry

Les performances d'autres drain à pierres sèches sont également résumées.

A ce jour, les résultats de l'opération et le contrôle des drains sont satisfaisants. En conclusion, la construction de drains perméables est généralement faisable et n'a pas d'impact sérieux sur la qualité et l'écoulement de la rivière. Le problème majeur est la performance à long terme de la structure et comprend; la solidité it la durabilité du remblayage, la stabilité de la pente en aval, l'impact sur la qualité de l'eau en aval dans des conditions normales d'opération et extrêmes de ruissellement.

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Une méthodologie rationnelle de la conception est présentée dans le rapport; toutefois, des améliorations seront certainement nécessaires avec l'accession à l'expérience du contrôle et de l'opération issues des applications en cours et de celles à venir. Cela fera le sujet d'une prochaine étude plus détaillée.

TABLE OF CONTENTS

		Page No.
1.	INTRODUCTION	1
2.	STUDY PARTICIPANTS	3
3.	STREAM HYDROLOGY AND SEDIMENT REGIME	4
4.	WASTE ROCK PROPERTIES	8
	4.1 GENERAL	8
	4.2 ROCK TYPES	8
	4.3 DEGREE OF SEGREGATION	9
	4.4 GRADATIONS	9
	4.5 STRENGTH	10
5.	ROCK DRAIN DESIGN	12
	5.1 LITERATURE REVIEW: PREDICTIVE METHODS FOR FLOW THROUGH ROCK FILL	12
	5.2 ESTIMATED FLOW CAPACITY OF WASTE ROCK	15
	5.3 RANGE OF FLOW CAPACITY	15
6.	PLANNING FOR WASTE DUMPS IN VALLEYS	18
	6.1 GENERAL DESIGN APPROACH	18
	6.2 DUMP/ROCK DRAIN PLANS OF STUDY PARTICIPANTS	18
	6.2.1. Smoky River Coal - No. 12 Mine Access Road Creek Crossing	19
	6.2.2 Crows Nest Resources Ltd. - Line Creek Mine	21
	6.2.2.1 Line Creek Rock Drain	21
	6.2.2.2 West Line Creek Rock Drain	23
	6.2.2.3 No Name Creek Rock Drain	23
	6.2.2.4 Monitoring Program	24

TABLE OF CONTENTS (Cont'd)

			Page No.
	6.2.3	Byron Creek Collieries - East Waste Dump	25
	6.2.4	Westar Mining Ltd. - Greenhills Operations	28
		6.2.4.1 Porter Creek Waste Dump	28
		6.2.4.2 North (Cataract Creek) Waste Dump	28
		6.2.4.3 Discussion	29
	6.2.5	Bullmoose Coal Mine - Y Creek Rock Drain	31
	6.2.6	Gregg River Resources Ltd. - Berry's Creek Rock Drain	33
6.3		CASE HISTORIES OF OTHER MINES REFERRED TO IN LITERATURE	36
	6.3.1	Fording Coal Limited	36
	6.3.2	Skyline Coal Mine, Scofield, Utah	37
	6.3.3	Colowyo Coal Mine, Colorado	37
	6.3.4	Eckman Park Coal Mine, Colorado	38
	6.3.5	Rockfill Across North Fork of Rose Creek	38
7.	MONITORING		40
8.	DISCUSSION		43
	8.1	GENERAL	43
	8.2	CONCLUSIONS	43
	8.3	RECOMMENDATIONS	44
REFERENCES			46

LIST OF TABLES

Table 1 Preferred Waste Rock Properties for Rock Drains

Table 2 Coal Mine Waste Dumps Rock Drain Survey

LIST OF FIGURES

Figure 4.1 Typical Range of Gradations for Coal Waste Dumps

Figure 6.1 General Location Map

Figure 6.2 No. 12 Mine Access Road Creek Crossing

Figure 6.3 Line Creek and West Line Creek Dumps and No Name Creek Overflow Channel

Figure 6.4 East Waste Dump

Figure 6.5 Porter Creek Dump Plan

Figure 6.6 Y Creek Rock Drain

Figure 7.1 Rock Drain Monitoring

LIST OF APPENDICES

APPENDIX I: SCOPE OF WORK

1. INTRODUCTION

In recent years, an increasing number of mines in mountainous terrain have concluded that placement of mine waste rock in valleys is the most economic and technically feasible means of waste disposal. The major drawback to this means of disposal is the impact that the fill will exercise on the stream occupying the valley floor. The major concerns centre on whether the stream flows will be disrupted and also, whether significant environmental effects will accrue downstream, either by way of increased sedimentation, or by chemical contamination (e.g. nitrogenous compounds). Also, it is important to examine the effect of the stream flow on the stability of dump, especially where it is located above an active facility, such as a sediment pond, access road or a plant site, or where a dump failure could cause major environmental disruption. The subject of rock drain design and construction practices was addressed in an international symposium held in Cranbrook, B.C. in September, 1986, where the current status of rock drain technology was summarized.

Piteau Engineering Ltd. was contracted by Supply and Services Canada (DSS) to undertake a systematic study to review the current approaches being followed by operating coal mines in the design and construction of rock drains, with a view to ultimately developing a common coherent approach to the topic of rock drain design, construction, monitoring and abandonment. To achieve this objective, a two-phase study is envisaged, comprising the following phases:

Phase I - Review of existing rock drain design and construction practices at operating mines;

Phase II - Field and analytical programs; preparation of research reports documenting the design, monitoring and operational procedures being utilized in rock drain construction at the respective mine sites.

The scope of work for the current Phase I study, as defined by DSS, is presented in Appendix I. In summary, the study entailed the following components:

a) literature review, preparation of work plan and summary of analytical procedures,

b) contact participating mines and other organizations to gather pertinent information on rock drains,

c) document methodologies used for predicting stream floods,

d) summarize procedures in use for rock drain design, construction, monitoring and abandonment, and,

e) document monitoring procedures and impacts associated with rock drain operations.

The findings of the study were summarized in a paper presented to the 4th Coal Operators Conference held in Tumbler Ridge, B.C. (Claridge, Thompson and Das, 1989).

2. STUDY PARTICIPANTS

Operating coal mines which participated in the study through interviews, or by providing relevant reports on the designs and performance history of specific dumps, are listed as follows:

* Byron Creek Collieries - East dump (Corbin Creek valley)
* Crows Nest Resources Ltd. - Line Creek, West Line Creek and No Name Creek dumps
* Smoky River Coal Ltd. - No. 12 Mine Haul Road
* Westar Mining - Cataract Creek
* Westar Mining - Balmer Operations
* Teck Bullmoose Mine
* Gregg River Resources Ltd. - Berry's Creek Haul Road

In the case of the Balmer Operations of Westar Mining, no waste dumps with rock drains are in existence or planned. Hence, other than for a site tour, no work was performed at this site for the study. Gregg River Resources Ltd. declined to participate in this phase of study, but has indicated an interest in becoming involved in any subsequent monitoring program related to a proposed rock drain for a waste dump planned in the Berry's Creek valley.

The study team gratefully acknowledges the cooperation and contribution made by the above named mines which agreed to share valuable information about the design and performance record of their respective rock drains.

Discussions have also been held over the past few years with governmental regulatory agencies in Alberta and British Columbia involved with permitting rock drain construction including:

Alberta - Energy Resources Conservation Board
- Ministry of Environment

B.C. - Ministry of Energy Mines and Petroleum Development
- Ministry of Environment and Parks

Discussions on the utilization of rock drains were also held with the Coal Association of Canada.

3.0 STREAM HYDROLOGY AND SEDIMENT REGIME

The primary function of the rock drains is conveyance of flows in a natural watercourse beneath a waste dump or access road. The generally accepted design flood for rock drains is that associated with the 1 in 200 year event. The mean daily discharge, rather than the peak instantaneous value of this flood, has been adopted in some rock drain designs. The rationale supporting this approach is that ponding is required at the inlet of the rock drain to achieve the necessary flow-through capacity. This ponding will attenuate the flood peak, but there are only a few hydrometric measurements to support the assumption. The difference in flows is significant; the peak will approach 1.7 to 1.9 times the mean daily discharge on watersheds with small drainage areas (<10 km^2). The hydrologic characteristics of the stream, volume available for ponding and watershed area all affect the degree of reduction of the peak flow.

The determination of the design discharge for the rock drain has been done using a variety of techniques including:

1. frequency analysis of flood discharges measured at the rock drain site
2. regional analysis of measured discharges of streams with similar climatological and physiographical characteristics
3. index-flood
4. rational method
5. rainfall - runoff models

The first technique is preferable, providing that the hydrologic records are of adequate length, continuity and quality. A considerable increase in confidence in the estimated flows can be gained by using record lengths in excess of 25 years, as compared to records shorter than 15 years. Often the watercourses within coal mining areas are not gauged or, if gauged do not have a sufficiently long record to enable a frequency analysis to be performed with confidence. The indirect estimation techniques are utilized in this situation.

The index-flood method uses the flood frequency curves for gauging stations within the hydrologically homogeneous region of the mine site. The floods at the desired return periods are expressed as a ratio of the mean annual flood. The mean annual flood must be estimated for the rock drain site, but a short period of record (<10 years) will suffice for the flood-index method.

The regional analysis technique also uses gauged flood flows at stations within the region, but relates extreme discharges to watershed descriptors such as drainage area and median elevation.

The rational method uses drainage area, rainfall intensity and a runoff coefficient to produce a peak value of surface runoff from a particular return period and duration of rainfall. More typically this method is applied to urban storm drainage; when applied to rural areas in excess of one square kilometer, the rational method may produce overly conservative, ie. high, flood discharges on larger drainage areas.

Rainfall - runoff models cover a broad scope of methods, including computer programs to transform rainfall intensity, duration and frequency data into runoff. Usually rainfall data for a mine site are available, or there is a long term record at a nearby meteorologic station, whereas stream flow data may be lacking. The transformation of rainfall to runoff using the physical parameters of the basin is an involved procedure and is normally undertaken when it is necessary to improve the precision of the calculated conveyance capacity required of the rock drain.

Rock drains are generally left in place for perpetuity, and design consideration must be given to floods exceeding the 1 in 200 year event. The probable maximum flood or PMF has been used as the ultimate flow a rock drain and its ancillary structures will have to withstand. The PMF is not derived from measured flood flows in the region, but is considered to result from the probable maximum precipitation that can be expected from the largest rain storm that has occurred in the region of the mine site. The PMF

criterion has been applied by regulatory authorities for flow-through rock drains where the implications of the failure of the rock drain conveyance capacity and contingency structures are perceived to be harmful. The rigorous calculation of the PMF can be a complex and lengthy process and index methods or standard hyetographs for particular regions such as those suggested by the U.S. Department of Agriculture, Soil Conservation Service, (1986) are often used for structures posing a minor hazard to personal safety or property damage. A rainfall-runoff-routing model or calculation procedure is used to transform rainfall to PMF flows. The PMF is ostensibly the highest flow a watershed would experience and natural erosion, debris flows, and flooding effects will be extensive. Some damage to hydraulic structures and minor failures of the drain and dump are therefore permitted within the PMF design scenario.

The sediment regime of the watershed in which the rock drain is located must be assessed to estimate the sedimentation time of the reservoir created upstream of the drain and the potential for plugging of the inlet face of the drain. Infilling of the inlet pond will occur as a result of the interception of bed load, and the settling of suspended solids in the quiescent water of the pond. There is also some concern that water-borne particles will settle or remain within the rock drain leading to plugging of the void spaces, progressively reducing the conveyance capacity of the rock drain. The interstitial velocities within the rock drain tend to be relatively high and the flow is turbulent, producing a condition non-conducive to settling. There is however, no conclusive evidence on either side of the above discussions. The sediment yield of the upstream watershed can be estimated (Barfield et al, 1985) using the Universal Soil Loss Equation (USLE), or the measured concentrations of suspended solids at, or near the location of the rock drain. This latter technique must use a factor to incorporate the bed load component since this represents a significant proportion of the total sediment load delivered to a rock drain in mountainous streams. Sediment buildup is more of concern in flow-through rock drains when compared to head of valley fills, where there is little or no drainage area above the rock drain.

The determination of particle size distribution within the suspended solids upstream of the rock drain has not been done in most of the coal mines surveyed. Although computer simulation models such as "SEDIMOT" (Wilson et al, 1981) include a module to estimate particle size distribution, the more direct and accurate method is to sample the suspended solids, primarily in the freshet when most of the sediment load is generated, and obtain the particle size distribution by laboratory analysis.

4.0 WASTE ROCK PROPERTIES

4.1 GENERAL

The ability of a waste dump to convey flow will depend on the physical properties of the rock contained in the dump. The most important physical property is the gradation, which controls the hydraulic conductivity of the waste. The rock gradation is, in turn, determined by the susceptibility of the various rocks types to degradation by mechanical and physico-chemical processes. Mechanical degradation applies to rock breakdown during mining and dumping. Physico-chemical breakdown applies to weathering processes which may cause further size decay following dumping.

The extent of mechanical degradation during mining is affected by various factors such as blasting, amount of handling, crushing if transported by conveyor, amount of rolling along the dump face, the loading of overlying material in the dump, the height of dumping and the over-all amount of impact energy that the rock is subjected to during placement. The relative susceptibility of different rock types to mechanical degradation can be evaluated by means of the Los Angeles Abrasion Test, as well as Unconfined Compressive strength tests, or Point Load strength index tests.

4.2 ROCK TYPES

At the coal mines surveyed, sedimentary waste rock consists of varying amounts of sandstone, siltstone and shale/mudstone. Sandstone and hard siltstone are the most resistant to mechanical and physico-chemical breakdown. These rock types are generally durable and are preferred for use in rock drain construction.

The relative proportions of durable waste rock available for rock drain construction varies among the mines, but in general would constitute over half of the total waste.

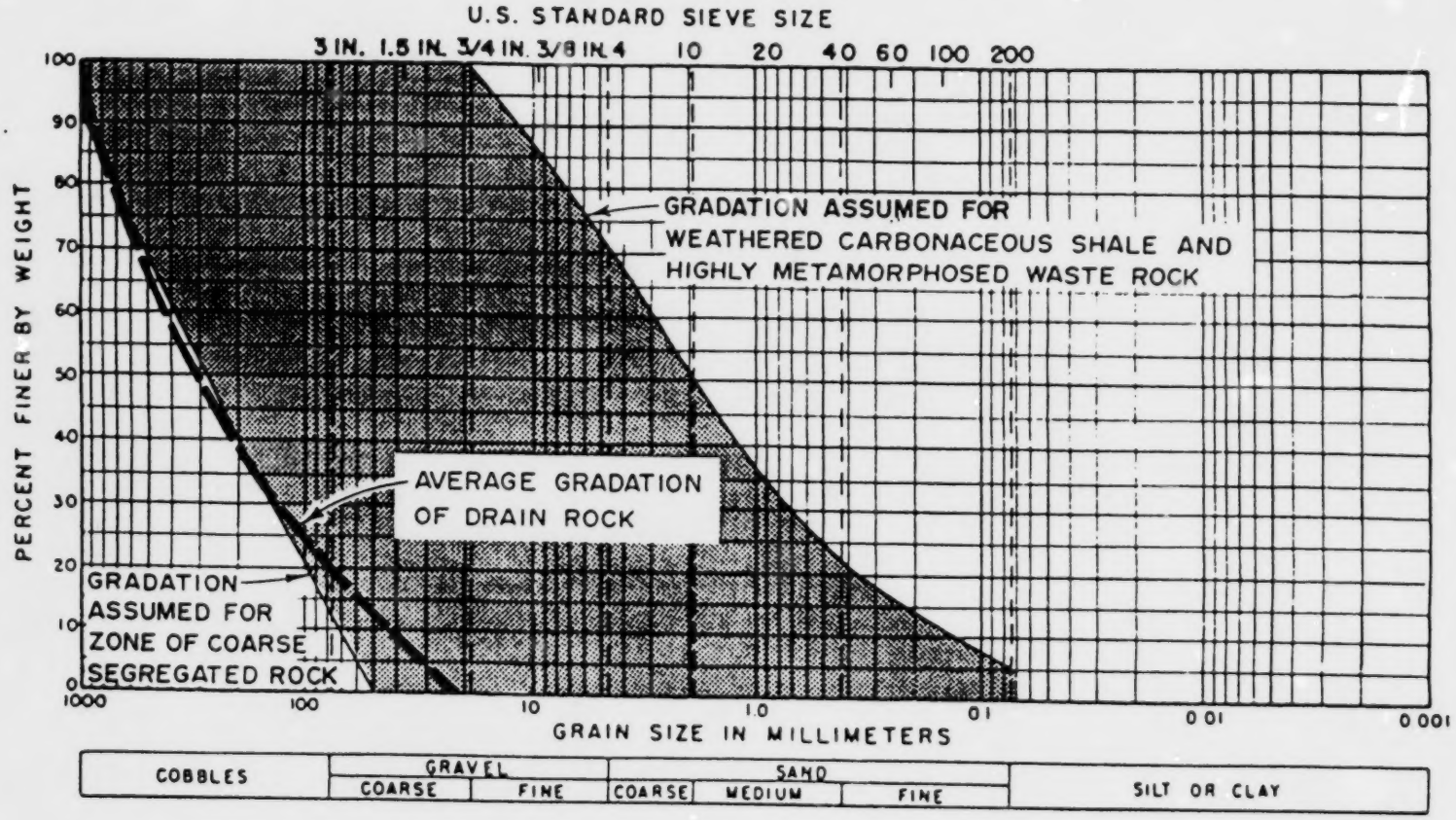
4.3 DEGREE OF SEGREGATION

An important feature of waste dumps is the tendency for larger and more durable rocks to roll to the bottom of the dump, forming a zone of coarse waste rock on the valley floor. This tendency was observed to varying degrees at all of the waste dumps surveyed.

A general relationship appears to exist between the height of a dump and the extent of segregation measured, at least up to a certain height. The minimum height of dump needed to establish a distinct zone of segregated rock appears to be in the range of 20 - 30 m. An additional height of dumping appeared to have resulted in somewhat coarser rock reaching the toes of the intermediate slopes to varying extents. In two of the dumps containing a high proportion of degradable waste rock and carbonaceous material, a relatively thin layer of segregated rock was observed to have formed, basically being only 1 or 2 rock sizes thick. An increased dump height in this case above the approximately 200 m height of dump would probably not have been beneficial to formation of a thicker rock drain.

4.4 GRADATIONS

Rock gradations constitute a wide envelope in practice, reflecting the wide range of material properties and extent of breakdown involved in the mining process. Figure 4.1 indicates a typical range of gradations encountered in sedimentary rock waste dumps in the Rocky Mountains region (Claridge et al, 1986). The significant part of this plot is the minimum gradation envelope, which to a large degree will control the hydraulic conductivity and thus, the flow capacity of the waste material. The minimum gradation is essentially a sandy gravel, with approximately 5% silt fines. This is important, because such a material will retain a relatively high hydraulic conductivity.



TYPICAL RANGE OF GRADATIONS FOR
COAL WASTE DUMPS

FIGURE 4.1

Mined waste rock from all of the dumps surveyed appeared to follow more or less within the gradation band shown in Figure 4.1; some of the mines tended to be on the finer side of the envelope.

4.5 STRENGTH

Based on work reported by Claridge et al (1986), a Los Angeles abrasion index of more than about 40% to 50% indicates a friable rock which will tend to decompose into fines during mining and dumping. Strengths in excess of approximately 50 MPa indicate a relatively hard rock which will tend to resist excessive breakdown during mining and dumping.

The potential for physico-chemical degradation can be evaluated by a slake durability test. A slake durability index of less than approximately 90% indicates a rock that will tend to break down excessively upon exposure to water. The durable fraction of the waste rock reaching the rock drain zone in all of the dumps inspected appears to satisfy durability criteria stated above and summarized in Table 1.

TABLE 1

PREFERRED WASTE ROCK PROPERTIES
FOR ROCK DRAINS
(From Claridge et al, 1986)

Rock Types	
Coal mines	- Sandstone
	- Hard siltstone
Metal Mines	- Igneous rock
	- Hard metamorphics
Mechanical qualities	
Los Angeles abrasion	<40%
Uniaxial compressive strength	>50 MPa
Physico-Chemical qualities	
Freeze/thaw	not significant at bottom of dump
Slake durability	>90%
Rock gradation	
Silt fines	<5%

5. ROCK DRAIN DESIGN

5.1 LITERATURE REVIEW: PREDICTIVE METHODS FOR FLOW THROUGH ROCK FILL

Pioneering work on flow-through rockfill concentrated mainly on the problems associated with flow-through rock and earth fill dams, and combined field experience of workers such as Weiss (1951) with laboratory observations such as those made by Izbash (1931) and Escande (1953). Recognizing the work of Dupuit (1863) and Forchheimer (1901), who argued that turbulent drag effects in fluids were proportional to the square of velocity, Escande concluded that flow through rockfill, with its relatively large voids, was turbulent, and therefore not governed by the laminar/linear Darcy equation, which ceases to be applicable above a Reynolds Number of 1. Escande developed the relationship:

$$V^2 = Bi$$

where V is the apparent velocity of water, i is the potential gradient, and B is an empirical constant.

Wilkins (1956, 1963) refined Escande's formula to include several other parameters, resulting in the expression:

$$V = CN^a m^b i^n$$

where:

V = average velocity of water through voids, in inches/sec,
C = shape factor for rock particles
N = viscosity of water,
m = mean hydraulic radius of rock voids, in inches,
i = hydraulic gradient,
a,b,n = empirical constants.

From laboratory data for clean crushed stone, values of the empirical constants were found to be: $a = 0$, $b = 0.5$, and $n = 0.54$. These values did not vary significantly for other types of rockfill. Laboratory work done by Parkin (1963) and Parkin et al (1966) verified Wilkins' formula, and was in reasonable agreement with the values of the empirical parameters a, b, and n. Wilkins' formula can be simplified by grouping the C, and a terms into an empirical constant W, which is a function of the shape and roughness of the rock particles, and the viscosity of water. This results in the expression:

$$V = W\, m^{0.5}\, i^{0.54}$$

According to Wilkins, W varies from about 33 inch.sec for crushed gravel, to 46 inch.sec for polished marbles. As discussed by Leps (1971), a practical determination of the mean hydraulic radius of the rock particles is possible for mono-sized rock, but becomes very difficult for a range of rock sizes which are present in most rockfills.

Leps (1973) presents a method whereby Wilkins' equation may be used for rockfills. In this method, the 50% grain size is considered the dominant particle size for flow calculations, provided that the material passing through a 1 inch sieve constitutes less than 30%, and preferably less than 10% of the total by weight. Above 30%, the material is closer to earth fill, and laminar flow conditions should apply for purposes of analysis. Although Thomas (1978) states that there is no basis for the selection of the 50% size, he agrees with the overall applicability of the method.

The practical effects of turbulent flow in rockfill include a higher phreatic surface than would be present in the laminar flow case, higher exit flow velocities, and higher pore pressures in many parts of the rockfill structure (Lawson, 1986). All these factors have implications for rockfill stability, and are discussed by Lawson (1986), Thomas (1978), and Leps (1971).

Prediction of flow and the phreatic profile within rockfill has been simplified by the application of computer techniques. Finite element models are particularly well suited to anisotropic fields and curved or irregular boundaries, such as are typically present in rockfills. Parkin (1971) describes a finite element program for calculation of non-linear flow-through rockfill, making use of variable triangular elements, and the variational technique for assigning piezometric head values at nodes. Similar solutions have been developed by Volker (1969), and Fenton (1968).

Analytical and modelling techniques are available for calculating the flow capacity of a rock drain and are reported in the literature (Leps, 1971, Parkin, 1971, Volker, 1971). However, the accurate application of these techniques is highly dependent on the accurate identification and determination of the following key physical parameters of the rockfill: material particle size and grading, void ratio and size distribution, bulk transmissivity, and piezometric levels within the rockfill. Due to the inherently variable nature of most rockfills, these parameters may be difficult to determine. Most authors caution that predictive techniques remain approximate and much additional study is required.

For example, in the formulation developed by Leps (1971), based on work done by Wilkins (1963), a nominal median rock size diameter must be assumed. Hence, the effect of grading on flow capacity cannot be directly determined. This limitation is probably not very significant where rock sizes are relatively uniform, as will usually be the case in the zone of segregated rock at the bottom of a dump, but will be important in the above lying, less segregated materials.

5.2 ESTIMATED FLOW CAPACITY OF WASTE ROCK

The magnitude of flow which can be transmitted along the bottom of the dump depends on a number of factors, the principal ones being:

a) creek gradient;
b) rockfill gradation, void ratio and corresponding hydraulic conductivity;
c) extent of rockfill homogeneity and presence of zones of relatively fine gradation waste rock;
d) extent of upstream ponding, which affects flow gradient;
e) length of dump along valley at time when flooding occurs.

The most important factors influencing through-flow capacity are the hydraulic conductivity of the waste rock and the continuity of zones of both high and low hydraulic conductivity rock. The latter factor is especially important, as zones of low permeability rock ultimately control the overall flow capacity of the dump.

5.3 RANGE OF FLOW CAPACITIES

The upper and lower bounds describing the potential range of flow which can pass through a dump should be estimated. Long-term ponding will not occur behind the dump if the mean annual stream flow can be transmitted. If not, long-term ponding can be expected, which may present an environmental problem. Knowledge of the potential maximum flow capacity is also useful in assessing possible effects of the flow on downstream structures, particularly if there is an on-stream sedimentation pond.

a) Minimum Capacity

The minimum flow through a dump can be anticipated where the dump consists of relatively degradable rocks, such as carbonaceous shale or mudstone (coal mines), or highly metamorphosed rocks, such as schist

or phyllite. A representative size gradation for highly degradable sedimentary and metamorphic rock is shown in Figure 4.1 as the fine boundary.

The hydraulic conductivity (K) corresponding to the finest gradation shown in Figure 4.1, which is equivalent to a well-graded sand, may be in the range of 3×10^{-4} m/sec. The minimum flow through the waste dump can be calculated by making the somewhat unrealistic, but conservative, assumption that the entire dump consists of fill having the minimum bounding gradation. The next step is to determine the depth of ponding associated with the "Project Design Flood (PDF)", usually the 200 year flood. Next, hydrological analyses should be conducted to indicate the depth of ponding associated with a flood flow ranging from the annual flood to as much as the "Maximum Probable Flood", or a percentage thereof. The flows through the dump corresponding to the range of potential ponding depths can then be calculated using a simple flow net procedure, or if justified, a computerized technique such as a two-dimensional steady state finite element or finite difference program for steady state flow (Cedergen, 1977; Freeze and Cherry, 1979). Usually, a hand-drawn flow net analysis is sufficient.

b) Probable Maximum Capacity

The maximum potential flow will occur if the bottom of the dump consists of a continuous zone of coarse segregated rockfill extending from one end of the dump to the other. The grain size distribution for typical coarse segregated rock is shown as the coarse boundary on Figure 4.1. The same procedure as described above can be carried out to determine the probable maximum flow through the dump.

c) Intermediate Capacity

In reality, because of a lack of coarse rock and possible slides, a continuous unbroken zone of coarse rock may not be developed along the entire length of the dump. The gradation of rock in the waste dump will likely be intermediate between the limiting extremes discussed in Section 4 (Waste Rock Properties) and illustrated in Figure 4.1. The main factor controlling throughflow capacity will be the gradation of the rockfill and hence the hydraulic conductivity existing within the bottom 10 m to 15 m of the dump. A realistic gradation of the bottom zone of material must be selected in order to determine the design flow capacity of the dump.

6. PLANNING FOR WASTE DUMPS IN VALLEYS

6.1 GENERAL DESIGN APPROACH

In planning a waste dump, consideration is given to the effects that a flood would have during interim dumping stages, as well as following completion of the dump. A critical situation may exist early in the dump life when the upstream ponding capacity is small and water may overtop the dump. This undesirable situation could cause extensive scour and a possible dump failure.

The over-all mine plan dictates whether dumping should proceed in an "upstream" or "downstream" direction. Depending on which direction is adopted, there should be some flexibility in constructing the critical downstream slope and toe of the dump. "Upstream" dumps allow construction of a relatively flat overall angle and therefore minimize the potential for a dump failure.

To minimize the potential for failure in "downstream" dumps, it is important to maximize the flow capacity at the dump base. This can be achieved by using a minimum lift height of about 20-30 m to ensure that natural segregation occurs. In addition, a high percentage of the placed rock should consist of good quality, durable rock.

6.2 DUMP/ROCK DRAIN PLANS OF STUDY PARTICIPANTS

Locations of the mining operations of the study participants and referenced rock drains are shown in Figure 6.1. The designs of waste dumps and rock drains at the respective operations are summarized in the following subsections. The main hydrological and rock drain design parameters and monitoring program elements are summarized in Table 2, at the end of Section 6.

6.2.1. Smoky River Coal - No. 12 Mine Access Road Creek Crossing

The Smoky River Coal Mine is located near the town of Grande Cache in west central Alberta (Figure 6.1). As part of the infrastructure developed for the No. 12 Mine, Smoky River Coal constructed a haul road crossing of 1.029 Creek. The crossing was achieved by means of a rockfill embankment, the lower portion of which consists of a through-flow rock drain constructed by selective placement of waste rock from the nearby South Pit. The embankment is 300 m long at the crest, has a maximum height of 20 m and a volume of 175,000 m^3. The rock drain portion of the embankment is 3 m thick and is designed to transmit the 1:200 year flood. The gradient of the creek channel is about 7.5 percent. A site plan and sections through the rock drain are presented in Figure 6.2.

The waste rock at the mine used for the construction of the rock drain was competent sandstone and siltstone. Laboratory tests on rock samples showed an average uniaxial compressive strength of 97 MPa for sandstone and 61 MPa for siltstone (both values exceeded the required minimum compressive strength of 50 MPa). Lab tests also yielded an average slake durability of 98.9% for the sandstone samples and 91.9% for the siltstone samples (also in excess of the minimum criterion).

The design 1:200 year peak flow rate was estimated to be 21 m^3/sec. No corresponding value of the mean daily flow was presented for the 200 year flood. The catchment area of the drainage basin is approximately 16 km^2. Based on the Leps-Wilkins relationship, the through-flow capacity of the rock drain was estimated to be 19 m^3/sec (Smoky, 1987 b).

The 1.029 Creek crossing was built in three stages, each consisting of a lift of 3 m, 9 - 15 m and 6 - 12 m, respectively (Smoky, 1987 a). The lowermost lift, which was the rock drain, was constructed from hard, durable select sandstone rock. It comprised an inner core, which consisted of rock sizes of diameter from 0.9 to 1.5 m and an outer core on either side consisting of rock particles with a mean diameter of 0.3 m. Both zones were

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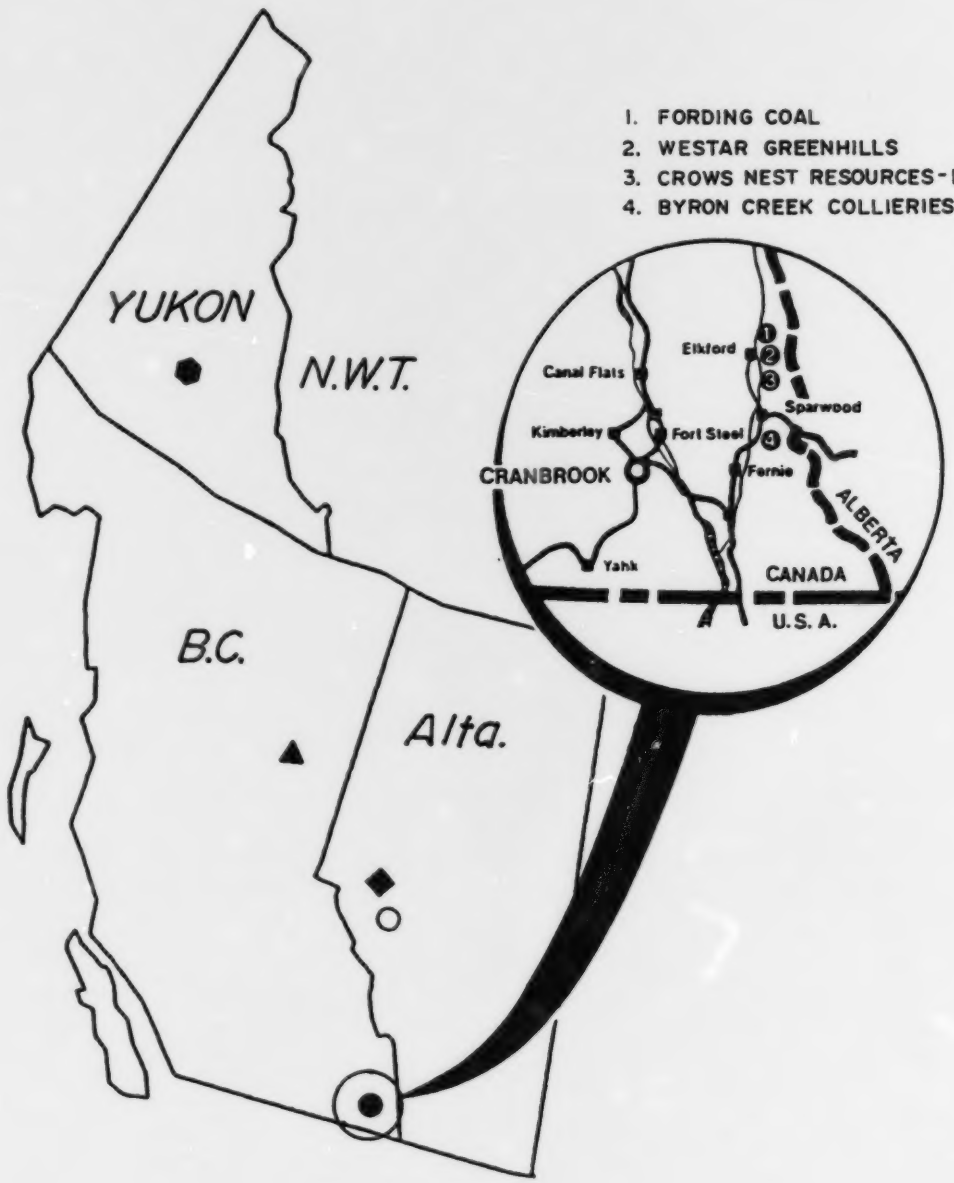

LEGEND

- (SEE INSET)
- SMOKY RIVER COAL
- GREGG RIVER RESOURCES
- TECK CORPORATION (BULLMOOSE MINE)
- ROCKFILL (NORTH FORK OF ROSE CREEK)

SOURCE: PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON FLOW-THROUGH ROCK DRAINS

REGIONAL STUDY OF ROCK DRAINS

GENERAL LOCATION MAP

FIGURE 6.1

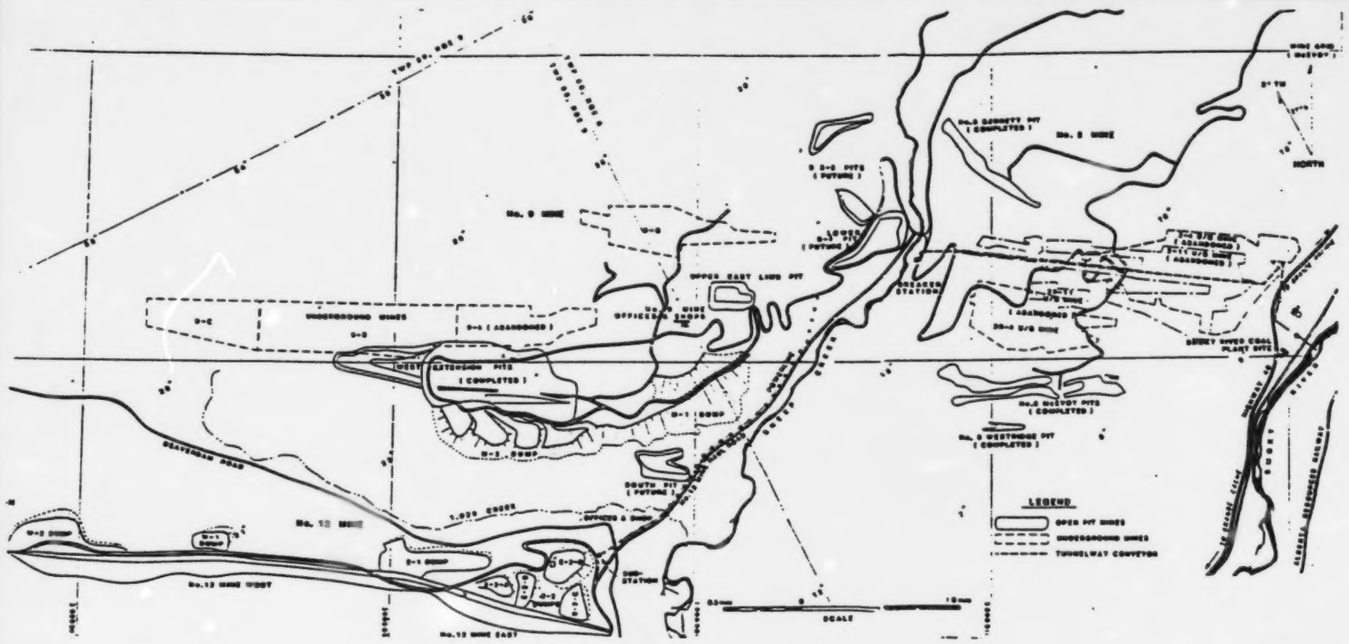

FIG. 6.2.1.A GENERAL LOCATION PLAN

N.T.S.

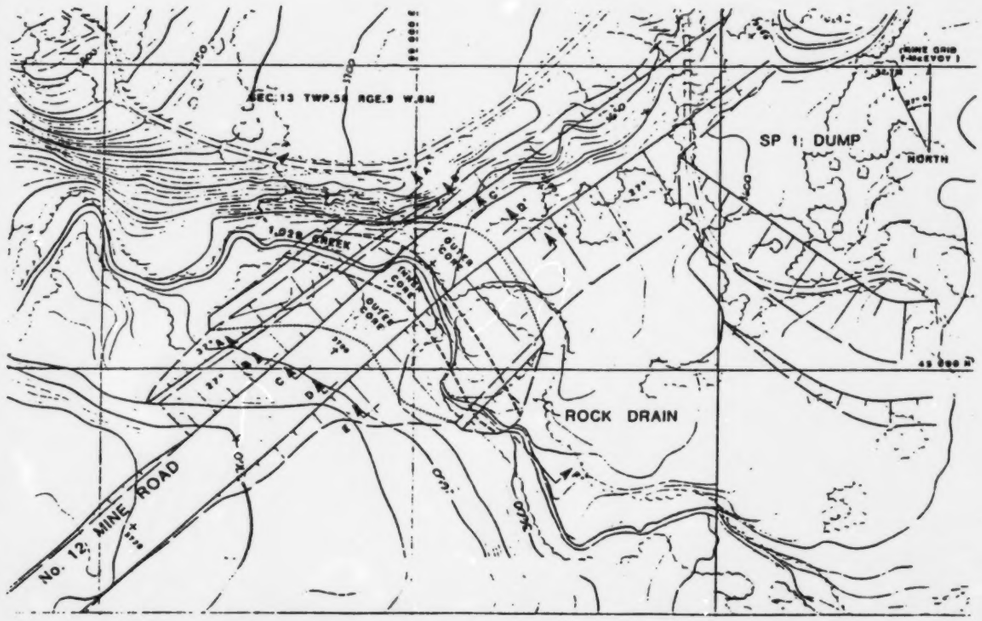

FIG. 6.2.1.B ROCK DRAIN LOCATION PLAN

0 100 200 300 400 500 ft.

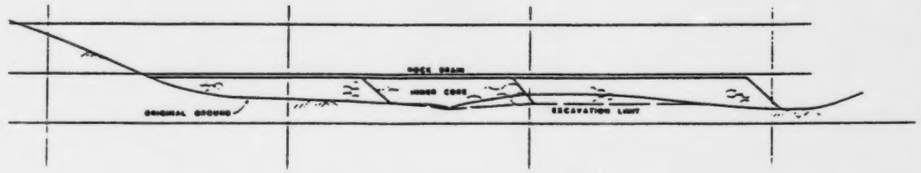

FIG. 6.2.1.C SECTION E-E

0 10 20 30 40 50 ft.

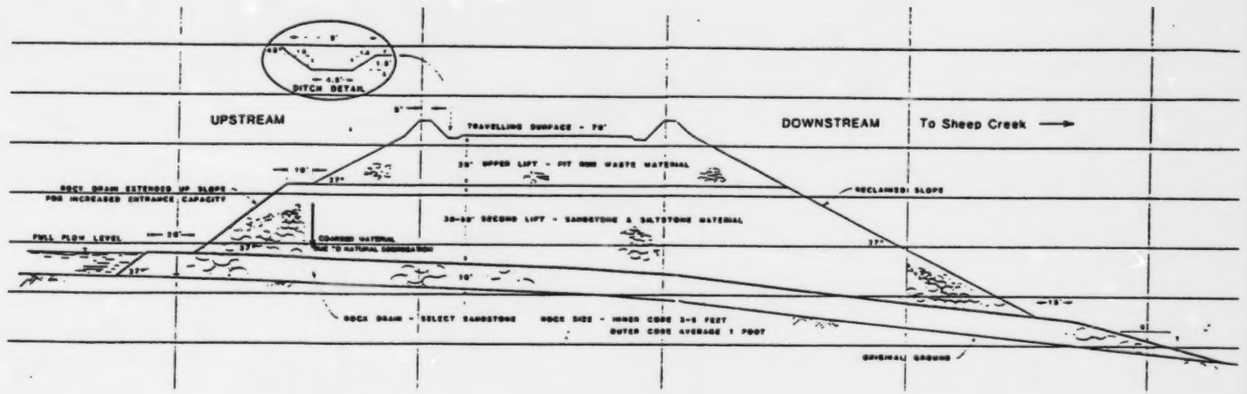

FIG. 6.2.1.D SECTION F-F

0 10 20 30 40 50 ft.

SMOKY RIVER COAL

No. 12 MINE
ACCESS ROAD CREEK CROSSING

FIGURE 6.2

constructed by end dumping the rock. A 1-foot layer of outer core material was placed on the foundation beneath the inner core to prevent any scouring action resulting during the placement of the larger size inner core material. The discharge face of the rock drain was sloped at 10° to prevent instability due to erosion, piping and ravelling.

The second lift was then constructed by end dumping select sandstone and siltstone from a height of 9 - 15 m. According to Smoky River Coal, end dumping from this height resulted in natural segregation of the coarsest rock fragments to the base of the second lift, further enhancing the entrance and hence, the flow-through capacity of the rock drain. The rock fragments used in the construction of this lift had an average size of 0.3 m.

The upper lift of the embankment was constructed by end-dumping pit-run waste rock over the second lift up to a height of 6 m. The haul road surface course was placed directly on the pit-run layer.

The monitoring program, which was conducted simultaneously with the construction and operation of the 1.029 Creek crossing, consisted of water quality sampling and measurement of suspended solids, iron, pH, copper, zinc, aluminum and manganese. In addition, a staff gauge was installed upstream of the drain to monitor water levels and to establish depths of ponding during storm events.

6.2.2 Crows Nest Resources Ltd. - Line Creek Mine

The Line Creek mine is located in the southeast corner of British Columbia between the towns of Sparwood and Elkford (Figure 6.1). Rock drains have been constructed at the base of waste dumps placed in the valleys of No Name Creek and West Line Creek. A major new waste dump and rock drain is planned in the valley of Line Creek, with construction to commence in mid 1989 (Reeves and Claridge, 1988).

6.2.2.1 Line Creek Rock Drain

The rock drain in Line Creek is designed to convey the 200 year mean daily flow of 37.5 m^3/sec. As the rock drain advances down the Line Creek valley, waste rock will be end dumped from a 150 m high lift over the rock drain surface at an elevation of 1675 m.

The gradient of the Line Creek valley is approximately 3 percent. It was assumed that a layer of large boulders 500 mm or more in diameter would form at the bottom of the lift which would be at least 2 m thick. The overlying rock fill in Zone 2 (Figure 6.3), which is estimated to be approximately 8 m thick, was assumed to have a minimum nominal diameter of 150 mm.

In order to convey the 200 year design flow of 37.5 m^3/s, the saturation level was calculated to be approximately 7 m above the valley bottom. The theoretical flow capacity in this zone was estimated to be 80 m^3/sec.

Figure 6.3 shows the sections through the inlet and outlet of the rock drain. The inlet is planned to be constructed of coarse sandstone with a minimum nominal diameter of 600 mm and a slope of 3 horizontal to 1 vertical to protect the upstream face from possible slumping following any potential ponding and subsequent drawdown of water within the dump. The downstream end will have a 20 m wide berm at mid-height to maintain the stability of the slope. The portion of the slope above the berm

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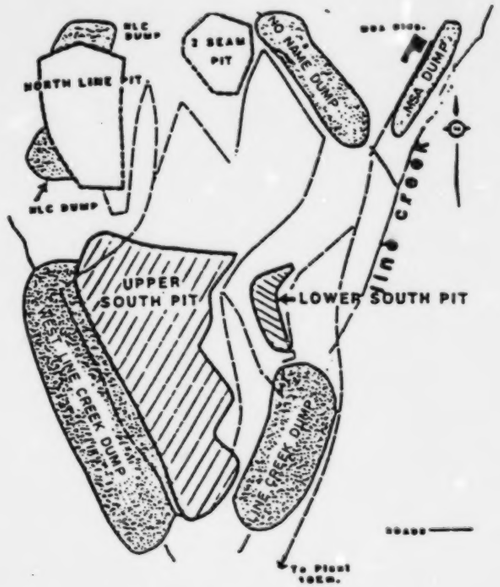

FIG. 6.3A GENERAL LOCATION PLAN

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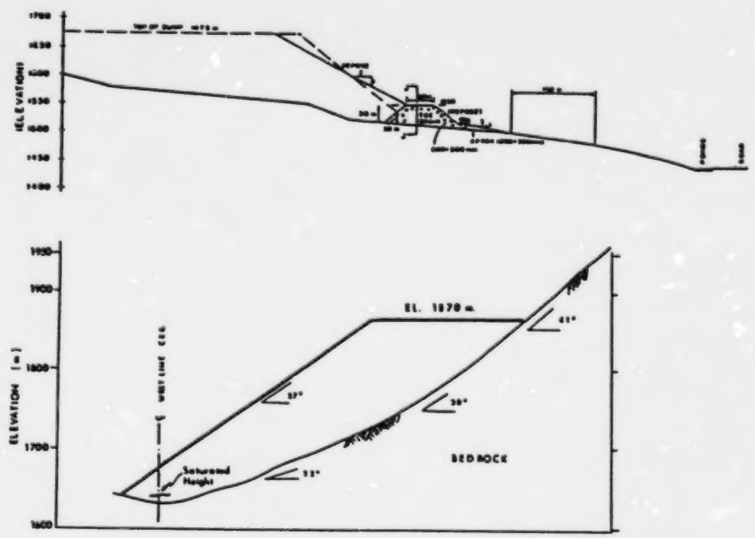


FIG. 6.3.B. WEST LINE CREEK DUMP
SECTIONS THROTUGH VALLEY & FINAL TOE

N.T.S

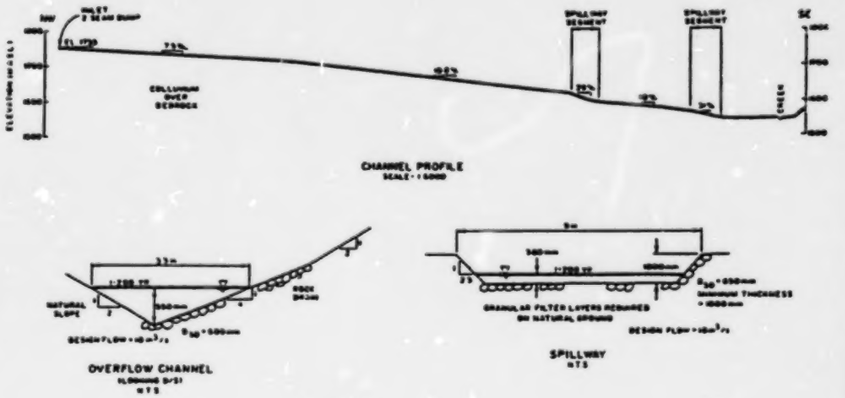
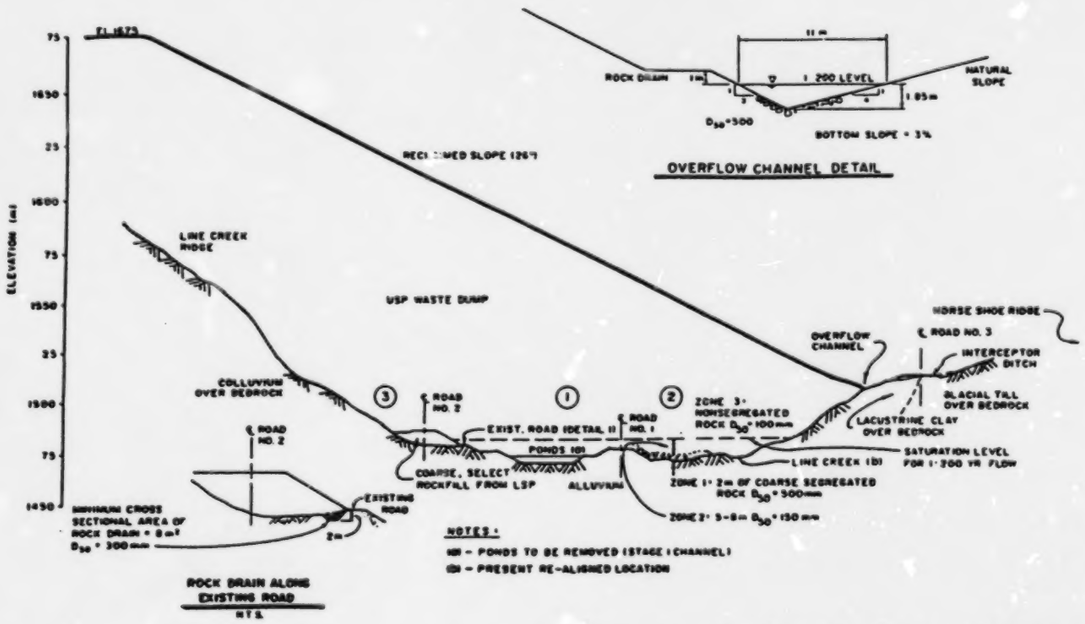


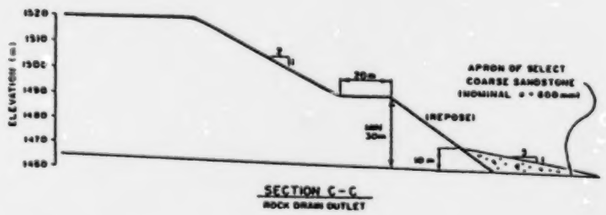
FIG. 6.3.C OVERFLOW CHANNEL PROFILE
NO NAME CREEK DUMP

N.T.S

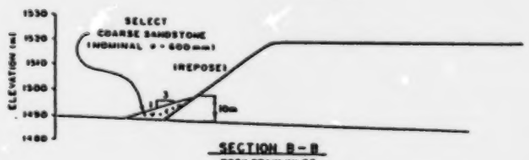

EL. 1875
RECLAIMED SLOPE 12H:1V
LINE CREEK RIDGE
USP WASTE DUMP
COLLUVIUM OVER BEDROCK
ROAD NO. 2
EXIST. ROAD (DETAIL II)
ROAD NO. 1
PONDS 101
COARSE, SELECT ROCKFILL FROM LSP
ALLUVIUM
ZONE 3: NONSEGREGATED ROCK D50 = 100 mm
ZONE 1: 2m OF COARSE SEGREGATED ROCK D50 = 500 mm
ZONE 2: 5-8m D50 = 150 mm
OVERFLOW CHANNEL
HORSE SHOE RIDGE
ROAD NO. 3
INTERCEPTOR DITCH
GLACIAL TILL OVER BEDROCK
LACUSTRINE CLAY OVER BEDROCK
SATURATION LEVEL FOR 1:200 YR FLOW
LINE CREEK 101
EXISTING ROAD
MINIMUM CROSS SECTIONAL AREA OF ROCK DRAIN = 8 m²
D50 = 300 mm
NOTES:
101 - PONDS TO BE REMOVED (STAGE I CHANNEL)
(2) - PRESENT RE-ALIGNED LOCATION

ROCK DRAIN ALONG EXISTING ROAD
NTS

OVERFLOW CHANNEL DETAIL



SECTION C-C
ROCK DRAIN OUTLET



SECTION B-B
ROCK DRAIN INLET

FIG. 6.3.D LINE CREEK ROCK DRAIN AND WASTE DUMP

N.T.S

CROWS NEST RESOURCES LTD.

LINE CREEK AND
WEST LINE CREEK DUMPS
AND NO NAME CREEK
OVERFLOW CHANNEL

FIGURE 6.3

will be reclaimed to 2:1, whereas the lower portion will be left at the repose angle. An apron of select coarse sandstone is planned at a slope of 5:1 in the outlet to prevent outflow the drain scouring the dump toe.

Since the inlet area available on the upstream face is much greater than the area required to conduct the 1:200 year flow through the rock drain, the overall performance of the inlet is not expected to be diminished significantly even if there is a reduction in hydraulic conductivity of the rock drain, due to accumulation of sand, gravel and other debris at the inlet of the rock drain.

The rock drain is planned to be constructed in stages both across and down the valley. The initial stage involves the clearance of a channel through the existing upper settling ponds, while Line Creek is diverted into the rock drain by removing an earth plug from the upstream end of the previously cut channel. Line Creek will be dammed below the point of diversion.

The second stage of the rock drain will be constructed with Line Creek flowing through the first stage drain. Surface preparation will consist of removal of trees and deep organic matter. The construction procedures will be repeated annually until the 1 km long drain is completed.

An overflow channel was designed for the 1 in 200 year mean daily flood flow of 37.5 m^3/s. This channel would flow along the east side of the dump and would serve as a contingency overflow in the event of long term plugging of the voids in the rockfill when the mine has been fully developed and abandoned.

6.2.2.2 West Line Creek Rock Drain

A flow-through rock drain has been in operation in the West Line Creek valley waste dump since 1981. A combination of hard, competent sandstone and siltstone waste rock was used for the construction of the rock drain. Dumping from a height in excess of 100 m resulted in a high quality rock drain being formed along a dump length of approximately 2.5 km in the West Line Creek valley.

A profile across the valley through the West Line Creek dump is shown in Figure 6.3, along with a section through the outlet. A toe drain berm is planned at the final toe to stabilize the outlet. The toe would consist of a 30 m high fill of 500 mm rock, buttressed by an apron having a foreslope of 5:1. The downstream slope of the toe drain would be left at the repose angle to ensure that the coarse segregated rock remains exposed to and in contact with the rock apron. It is planned to reclaim the slope above the toe drain to an inclination of 2:1.

A 1 in 7 year flood was experienced by West Line Creek in May, 1986. The peak flow was greatly reduced by the dump, with the maximum recorded flow being 1.1 m^3/s. The peak instantaneous and mean daily discharges estimated for this return period exceeded 11 and 7 m^3/s respectively.

6.2.2.3 No Name Creek Rock Drain

The No Name Creek waste dump has a capacity of 15 million bank m^3. In the lower portion of the dump near the outlet of No Name Creek, a rock drain was constructed from select sandstone and hard siltstone, which were obtained from mining the Lower South Pit. The rock was specified to have a mean size of 300 mm. It was dumped from a height of approximately 20-30 m. Sufficient segregation occurred for the drain to convey flow at a velocity comparable to that predicted by the Leps-Wilkins equation, as confirmed by dye tracer tests.

The estimated depth of saturation corresponding to the 200 year flood flow is approximately 5 - 8 m above the valley floor.

An overflow channel was designed for transmitting the 1 in 200 year flood in case the rock drain plugs with sediment or debris over time. A section across the channel is shown in Figure 6.3.

6.2.2.4 Monitoring Program

Monitoring of the rock drain at the Line Creek project is planned to include flow measurements, channel surveys, dye tests and water quality studies.

The monitoring program for the West Line Creek and No Name Creek projects included water quality monitoring (involving monthly samples between June 15 and March 15 each year and weekly samples between March 15 and June 15), and sampling of suspended solids. The West Line Creek rock drain was found to be clear enough to be directed straight into Line Creek and needed no treatment after flowing through the 2.5 km rock drain, although settling ponds are available. By contrast, the flow emerging from the No Name Creek dump frequently contains suspended sediment at concentrations requiring treatment in settling ponds. This is due to sediment in the creek flows entering the dump. The sediment is generated mainly from logging roads and other disturbance upstream of the dump.

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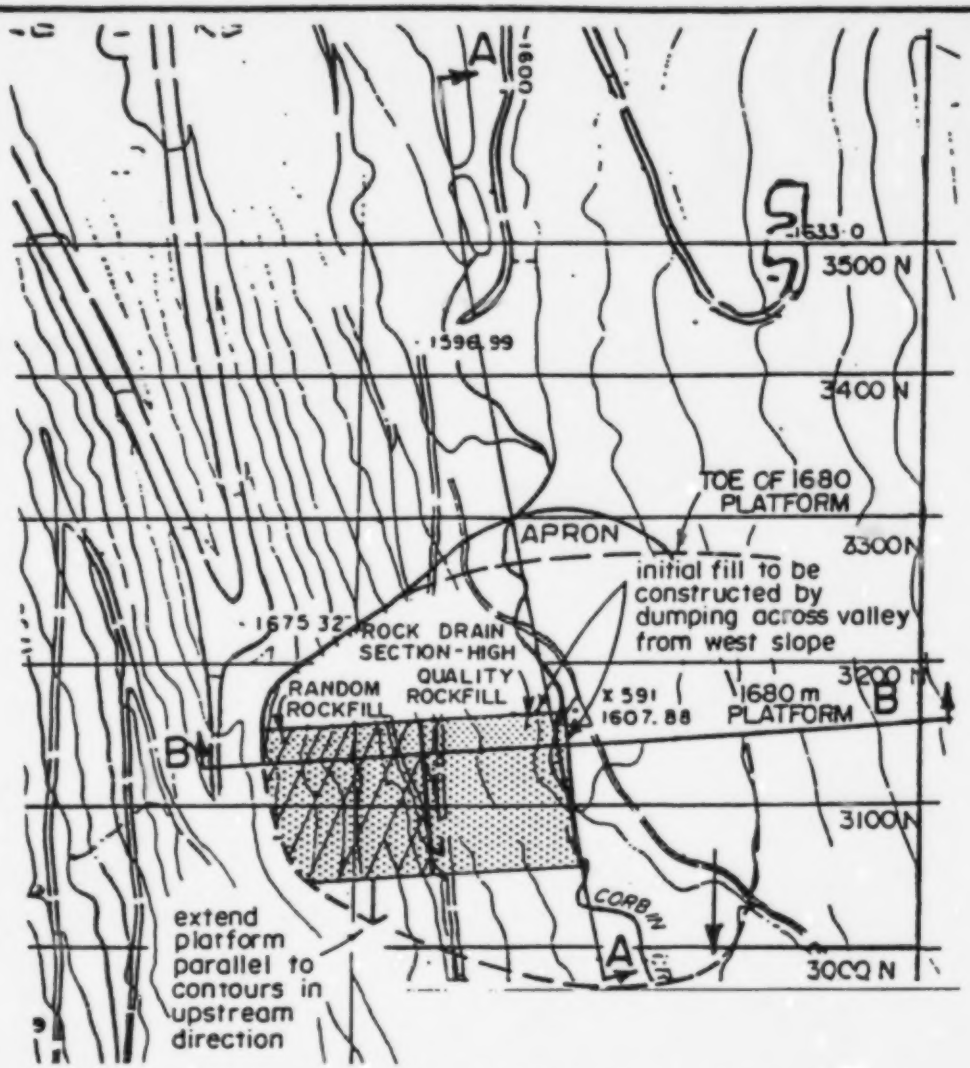


FIG. 6.2.3.A LOCATION PLAN - 1680 m PLATFORM

0 100 200 m

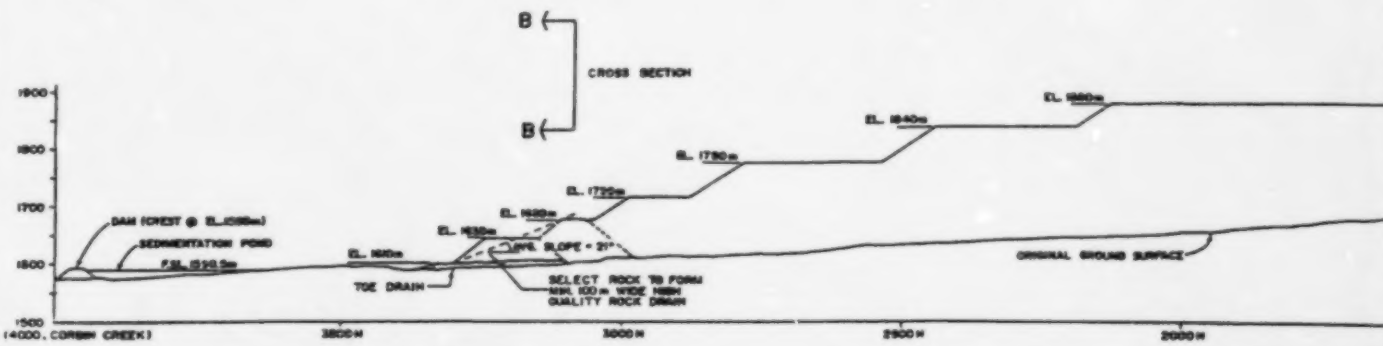


FIG. 6.2.3.B LONGITUDINAL SECTION A-A

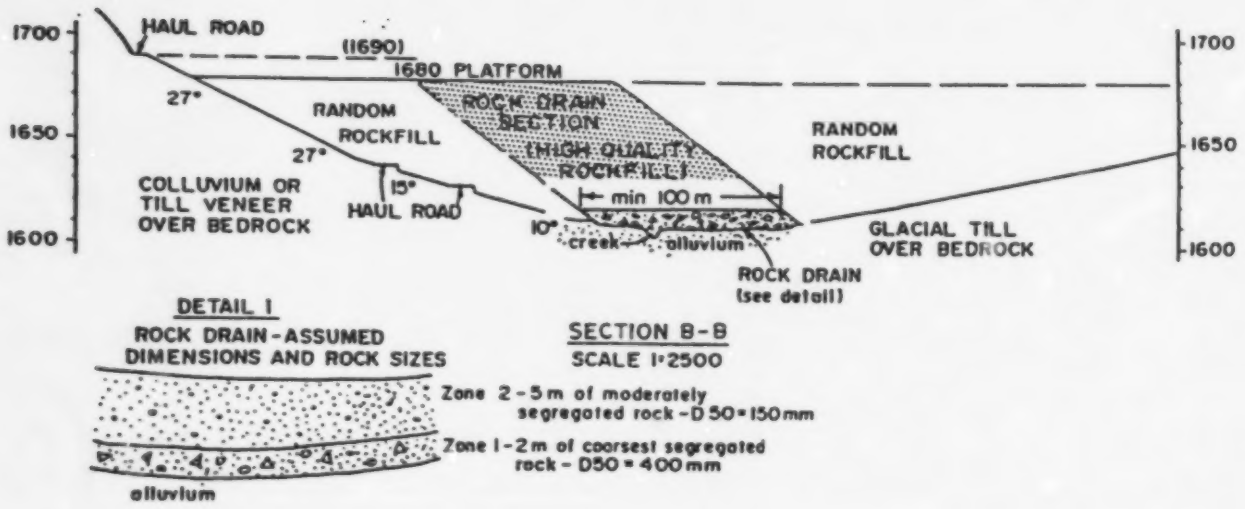
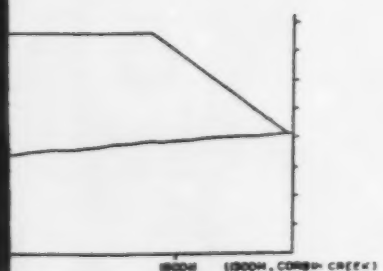


FIG.6.2.3.C CROSS SECTION B-B

0 50 100 m



BYRON CREEK COLLIERIES
EAST WASTE DUMP
FIGURE 6.4

6.2.3 Byron Creek Collieries - East Waste Dump

The East Waste Dump was designed to accommodate approximately 323 million loose cubic metres of waste material. A site plan is shown in Figure 6.4 and shows the dump outline within the valley of Corbin Creek. The maximum height of the dump is planned to be approximately 220 m. For reasons of effectiveness and long-term performance, a rock fill drain beneath the dump was chosen as the preferred alternative for conveying the flow of Corbin Creek, rather than through a culvert or in a sidehill diversion. The dump toe was located approximately 300 m upstream of an existing storage reservoir - sedimentation pond. To ensure the stability of the critical downstream face of the dump, select rockfill will be dumped from the 1650 m level platform, at a height of approximately 45 m to form a minimum 100 m wide rock drain. This zone of high quality rock drain material will extend approximately 200 m into the dump from the rock drain outlet.

The rock drain was designed to convey at least the 1 in 200 year return period mean daily flood flow of 8.8 m^3/s. The average natural hydraulic gradient along the Corbin Creek valley between the upstream and downstream toes of the dump is approximately 5 percent. The average velocities of water in the rockfill consisting of rock particles of 150 mm, 300 mm and 600 mm diameter were calculated as 0.14, 0.20 and 0.29 m/s respectively. Both the hydraulic gradient and the water velocities were calculated assuming that no ponding occurred at the upstream toe of the waste dump. Theses values would increase if ponding occurs.

Construction of the waste dump commenced along the west valley wall in early 1989, although the creek has not yet been crossed. Rock fragments comprising the waste dump were angular and relatively well-graded, ranging from a maximum diameter of 1-2 m, down to a small proportion of sand sizes. The base of the dump consisted of relatively coarse rock sizes, which accumulated by segregation during construction of the waste dump by end dumping. The angular shape of the rocks was considered generally favourable for slope stability, since an element of interlock increased its strength.

The underdrain rockfill was specified to consist of select, hard sandstone having a point load compressive strength in the range of 79 to 213 MPa, which was considered sufficient to prevent excessive fracturing under impact or static loading of the overlying waste rock.

In addition to constructing a high quality rockfill underdrain in the downstream portion of the dump, the stability of the downstream toe of the dump will be enhanced by placing platforms of select (Class "A") rockfill[1] at intermediate elevations of 1610 m and 1650 m, thus limiting the height of individual platform slopes to 40 m. The 1650 m platform will be used for constructing a toe rock drain, as discussed above. An apron of Class "A" rockfill will also be placed in the outlet of the dump below the elevation 1610 m berm. The apron will be sloped at 5:1 to prevent scour by flows emerging from the dump toe. For the design flow, the height of exiting water was estimated to be less than 1 m and the velocity of water in the voids approximately 0.2 m/s.

Due to the high permeability of the rockfill in the dump, little ponding was expected at the upstream end of the dump during periods of high flow.

Foundation preparation for the area of the toe drain consisted of clearing trees and stripping any organic material exceeding a depth of approximately 200 mm. The select rockfill material was dumped directly into place from the respective platform levels.

A longitudinal section through the slope is shown in Figure 6.4. The overall angle of the downstream slope below the 1680 m platform is 21°. The slope below the 1650 m platform was planned to be left at the repose angle to ensure that the coarse rock forming the rock drain at the bottom of the dump lift is not covered by finer rockfill, which would be the case if the slope is reclaimed.

---

1. Class "A" rockfill defined as being select, hard sandstone and siltstone rock having a minimum nominal size of 400 mm.

NORTH
(CATARACT CREEK)
DUMPS
PORTER
CREEK DUMPS

WESTAR MINING LTD.

PORTER CREEK DUMP
PLAN

FIGURE 6.5

As shown in the figure, two zones of segregated rock are anticipated to form at the bottom of the dump. The bottom zone (Zone 1) of coarsest rock is estimated to be 2 m thick with a median rock size of 400 mm. Above this, a 5 m thick zone (Zone 2) of moderately segregated rock with a median diameter of 150 mm is assumed to be formed. Zone 1 would convey the 200 year return flow of 8.8 m^3/s, whereas Zone 2 would provide additional capacity in case of a flood event, as well as prevent any potential plugging by fines, and would have a flow capacity of 6.6 m^3/s. The combined capacity of Zones 1 and 2 was estimated to be 15.4 m^3/s, well in excess of the 200 year mean daily flood flow of 8.8 m^3/s.

After the waste dump has crossed Corbin Creek, a monitoring program will be implemented and will include measurement of flows into and out of the drain, suspended sediment concentrations and ponding levels at the inlet. Consideration is also being given to installing piezometers below the 1650 m berm near the outlet of the rock drain.

6.2.4 Westar Mining Ltd - Greenhills Operations

Two waste dumps have been constructed in small catchments adjacent to Cougar Pit of Westar Mining's Greenhills Operations. The sites are located approximately 12 km northeast of Elkford in Southeastern B.C. The dumps are described as follows:

6.2.4.1 Porter Creek Waste Dump

The Porter Creek Waste Dump is located in the east tributary of the Porter Creek Valley, as shown in Figure 6.5. The catchment area within and above the dump is approximately 0.25 km. Porter Creek (in the dump area) is relatively straight with a slope of about 8-12% at the base of the dump. A short distance downstream, the slope steepens sharply to about 25% for about 200 m, after which it gradually decreases until it enters the Fording River floodplain. The 200 year mean daily flood flow was estimated to be 2.95 m^3/sec (Piteau, 1985).

There has been only a minor increase in suspended sediment due to the construction of the dump. However, dumping into the creek caused an initial short-term impact until the fill placement was above the creek bed and the flow through the dumped material had expelled the fines. For this reason, construction of a small sedimentation impoundment was constructed below the waste dump. This impoundment was 4 m in depth, with an area of 1300 m^2.

6.2.4.2 North (Cataract Creek) Waste Dump

A total of 303.5 million m^3 of rock is planned within this dump. The catchment area within and above this dump is 1.5 km^2.

A series of sediment collection ditches and a small sedimentation pond were constructed to remove suspended solids from the water. These solids, consisting of sand and silt fines, tend to be washed out from the coarser waste rock as it is dumped and transported downstream.

A coarse rock underdrain was observed to form in the dump due to the natural segregation that occurred during end dumping. Potentially adverse conditions that were identified during the design phase, but were successfully avoided during the dump operations were: (a) mixing organic and/or weak foundation materials with coarse rock which might have prevented free drainage, (b) placement of fine waste rock (including pre-strip materials) in the foundations, and (c) the occurrence of large sloughs at the active dumping face, resulting in deposition of finer materials from the crest elevation level to the toe area.

6.2.4.3 Discussion

The dump performance monitoring program comprised visual inspections, collection of dumping records and utilization of simple crest deformation monitoring equipment. Dye tests have been used to measure flow velocities within the Porter Creek dump, which were estimated to be in the order of 0.2 m/s.

The dump surfaces were sloped so that surface runoff was directed away from active dumping locations, and hence water was not allowed to pond on the dump surface. The quality of discharge water has generally been acceptable and lower than the allowance suspended sediment level of 50 ppm.

Both waste dumps have performed satisfactorily. The Porter Creek dump has undergone no significant failures, although the North dump did experience a flow slide which travelled down the valley, stopping above the sediment trap. The slide did not impede flows from the rock drain, which has performed well. Waste rock in the dumps is relatively poor, containing an estimated 20 percent of friable mudstone and carbonaceous material, compared with only 10 percent sandstone rock. The remaining rock consists of variable quality siltstone. The rock tends to be finer than at other mines because of higher intensity blasting and

fragmentation needed to limit maximum rock sizes to approximately 0.5 m to facilitate loading with a hydraulic shovel. No ponding has been observed at the inlet to either dump rock drain.

In spite of the predominance of fine rock sizes, a thin layer of coarse rock has developed in the dump bottom to form a rock drain. However, this layer is only 1 or 2 boulders thick on the average. The boulders average 300 - 500 mm in diameter.

A novel feature of the Porter Creek dump is that it has been utilized for disposal of water pumped out of the Cougar East Pit. The water is pumped at a rate of approximately 15 litres per second into sumps and allowed to seep into the dump. The discharge water is usually slightly silty, but much cleaner than the mine water which is being pumped into the sumps.

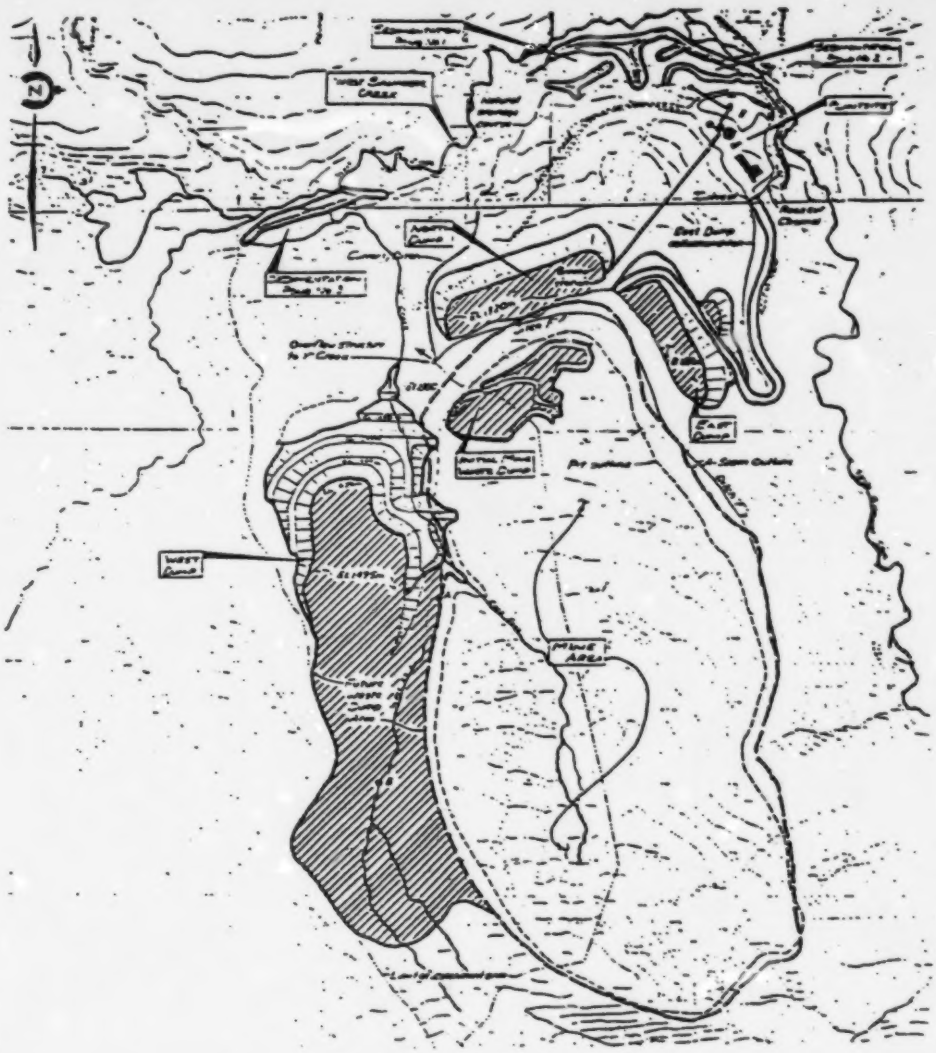


FIG. 6.2.5.A PLAN OF BULLMOOSE COAL MINE

N.T.S.

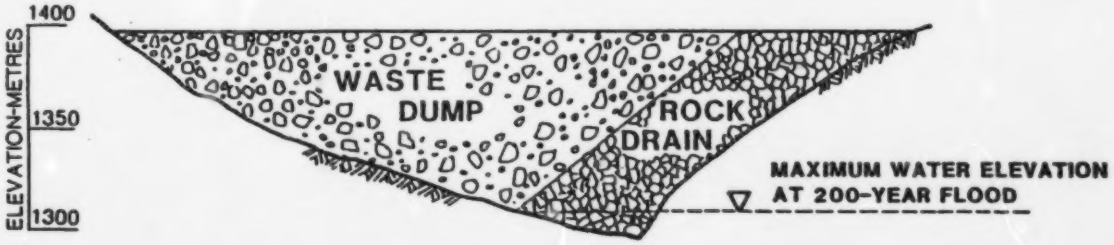


FIG. 6.2.5.B FLOW-THROUGH ROCK DRAIN

50m 0 100m

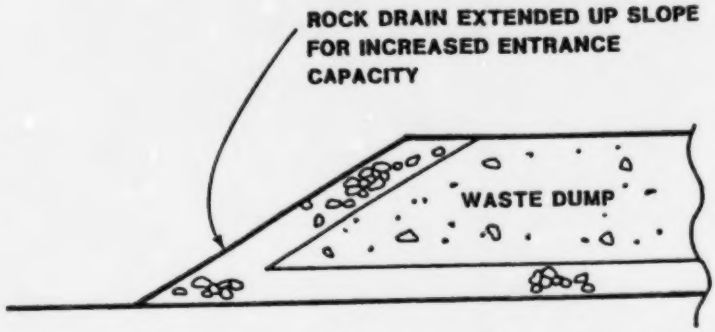


FIG. 6.2.5.C UPSTREAM SLOPE OF WASTE DUMP

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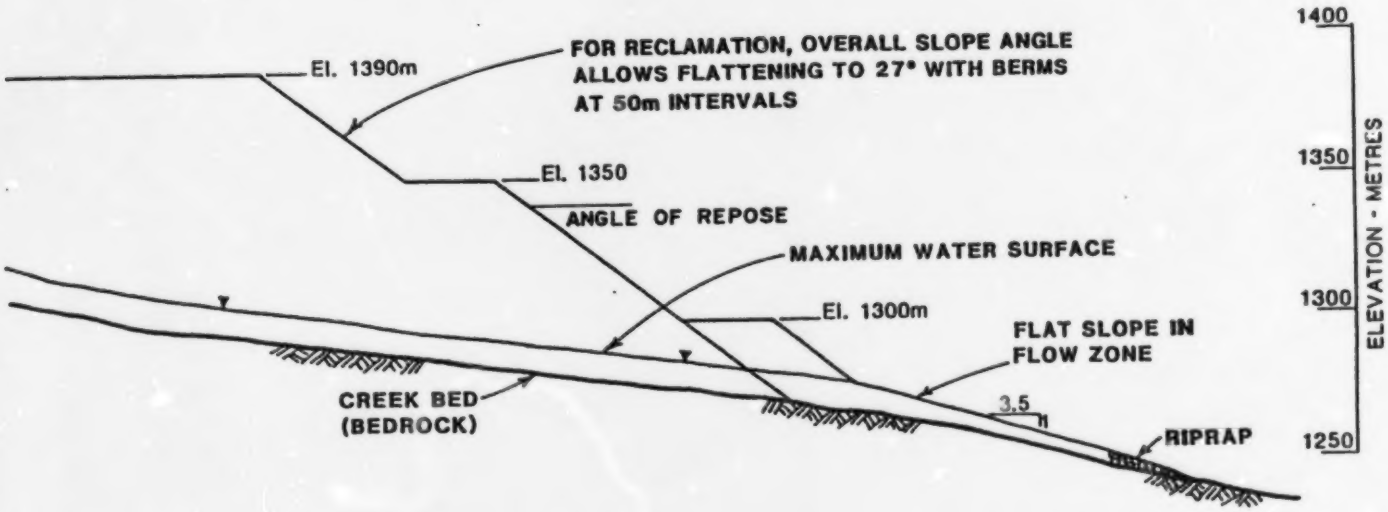


FIG. 6.2.5.D DOWNSTREAM SLOPE OF WASTE DUMP

0 50 100 m

BULLMOOSE COAL MINE
Y CREEK ROCK DRAIN
FIGURE 6.5

6.2.5 Bullmoose Coal Mine - Y Creek Rock Drain

The Bullmoose Coal Mine is located in the northeast coal development of British Columbia (Figure 6.1). Figure 6.6 shows a plan of the development of the mine. A waste dump and rock drain were constructed in the valley of Y Creek in 1983.

The waste rock at Bullmoose was of good quality, consisting of 40% hard, durable sandstone, 40% medium strength siltstone and 20% lower strength, degradable mudstone/shale. Point load index tests performed on selected sandstone samples yielded an unconfined compressive strength of 125 to 165 MPa. Slake durability and magnesium sulphate soundness tests carried out on sandstone samples indicated that the material was resistant to weathering and chemical breakdown.

The design data for the Y-Creek rock drain were as follows:

Average rock size:	300 mm
Rock size after breakage:	240 mm
Initial void ratio:	0.7
Final void ratio:	0.6
Hydraulic gradient:	0.08
Design flow:	25.7 m^3/s (200-year flood)
Void velocity:	0.17 m/s
Mean velocity:	0.064 m/s
Cross-sectional area:	400 m^2
Typical flow depth:	12 m
Minimum drain height:	20 m

The construction of the waste dump drain involved the placement of a high lift at elevation 1390 m near the downstream end of the Y Creek drain. Subsequently, berms were added at elevations 1350 m and 1300 m. Partial drain sections were also placed as creek crossings at several upstream locations (Lighthall, 1985).

Figure 6.6 shows a typical section through the waste dump and rock drain. As shown in the figure, the maximum water level in the rock drain during the 200-year peak flow would be about 12 m above the creek bed.

A typical section of the downstream slope of the waste dump along the alignment of Y Creek is shown in the figure. A toe berm was designed in the creek section to accommodate the high water levels at the outlet during peak flow. The slope was planned to be flattened to 3.5 horizontal to 1 vertical, with a riprap toe. Berms were left at 50 m intervals in the overall waste dump to allow the slopes to be flattened to 27° overall.

The performance of the rock drain is reported to be satisfactory, with all the flow being carried by it and no blockages have been observed to date (Lighthall, 1989 and personal communication with Bullmoose operating corporation, 1989). Flows have also been free of sediment that was observed initially after construction. A formal water quality monitoring program is planned to be implemented during the latter part of 1989.

One of the modifications adopted since construction of the downstream slope was the elimination of the flattening berm at the toe of the dump. This did not result in any instability during high flows, except for minor ravelling at the toe.

In conclusion, the rock drain was considered to have the following advantages;

- convenient waste disposal location in valley;
- avoidance of expensive stream diversion and erosion control measures;
- flexibility in dump construction;
- construction at no cost to the mine other than requirement for selective disposal of waste rock;
- significant flood routing effect resulting in a reduction of downstream spillway construction costs.

6.2.6 Gregg River Resources Ltd. - Berry's Creek Rock Drain Crossing

Gregg River Resources Ltd. (GRRL) operates the Gregg River Mine; an open pit metallurgical coal mine situated approximately 40 kilometres south of Hinton, Alberta. The mine is located along the eastern slope of the Rocky Mountains.

Regional hydrology of the minesite is dominated by a series of valleys (Gregg River, Camp Creek, Berry's Creek, Falls Creek and Sphinx Creek from southeast to northwest) that trend generally perpendicular to the strike of the coal structure and designated mining areas. Mining on the property started in 1982 and up to 1987, concentrated on six mining areas between Gregg River and Berry's Creek. Pit development west of Berry's Creek was initiated in 1987 by accessing this area via a haul road over the creek and incorporating a rock drain to convey flow.

The catchment area of Berry's Creek above the rock drain crossing is 1220 ha. Based on a 1 in 100 year rainfall having a 24 hour intensity of 230 mm, the 1 in 200 year return period average flow rate and peak flow rate were estimated at 24.4 m^3/sec and 48.0 m^3/sec, respectively. A design conveyance rate of 40 m^3/sec was selected for the rock drain crossing, which is estimated to provide capacity in excess of the average flow for a 1:1000 year rainfall event.

Using the turbulent flow relationships developed by Wilkens (1956) and Leps (1973) to predict velocity of water flow through rockfill, a D50 rock size of 600 mm was determined to be desirable for use in the rock drian. A void ratio of 0.33 (25% porosity) was assumed for the rockfill. The following design parameters were established for the rock drain:

average flow-through velocity = 0.20 m/sec and
cross-sectional area of drain = 790 m^2.

The rock drain portion of the crossing was constructed entirely of footwall sandstone rock. Field investigation of this material exposed on existing pit walls and placed in active dumps and properties (hardness, core recovery, Rock Quality Designation and degree of breakage) determined from diamond drill core indicated that the footwall sandstone was suited to rock drain construction.

Laboratory testing of the sandstone, as summarized below, indicated that this material would withstand mechanical degradation during placement and weathering processes within the drain:

Unconfined Compressive Strength:	160 MPa
Slake Durability Index:	98.8%

Site preparation for the rock drain included removal of all timber and topsoil salvage along the valley floor. Construction of the rock drain started with selective placement of a coarse (900 mm - 1200 mm) zone of rock down the creek channel. This rock drain core was designed to have a cross-sectional area of 25 m^2 and required 4600 m^3 of material. Once in place, the main body of the rock drain was constructed by end-dumping suitable rock (footwall sandstone, D50 of 600 mm) from a height of 12 m across the valley. The total volume placed in this phase of construction was 130,000 m^3.

Prior to placement of the final road fill (15-20 metres on top of the rock drain), a 1200 mm diameter culvert was placed on the top surface of the rock drain to serve as a contingency overflow in the event that the flow-through capacity of the rock drain should diminish over time.

Four standpipe piezometers, two at the upstream and two at the downstream faces, were installed to monitor flow elevation within the drain. Additional monitoring has included:

- stream flow measurements upstream and downstream of the rock drain
- particle size analysis of suspended solids at the inlet and outlet
- post-construction analysis of aquatic biota (benthic invertebrates) at upstream and downstream locations
- upstream and downstream pH and iron level analysis.

Development of a major valley fill dump across Berry's Creek upstream of the haul road rock drain is currently being planned.

6.3 CASE HISTORIES OF OTHER MINES REFERRED TO IN LITERATURE

6.3.1 Fording Coal Limited - Swift Creek Dump

The "C" spoil waste dump at Fording Coal Limited's Greenhills mining area crosses the Swift Creek drainage course. Although waste rock was dumped directly into the stream course, as a precaution in case the flow capacity within the bottom segregated zone was insufficient, a layer of select coarse rock was placed adjacent to the stream channel to serve as an overflow collector. It is understood that the creek flows to date have been conveyed satisfactorily by the dumped rock in the creek bed and it has not been necessary to utilize the artificial drain. Rock drain construction was commenced in 1980.

The maximum measured water flow through the Swift Creek Rock Drain during the 5 years it has operated is 1.7 m^3/sec (Lane, 1986). From piezometer data, it was found that the through-flow capacity of the coarse rock layer remained essentially constant for 4 years and has not diminished with time (Lane, 1986 and Campbell, 1986).

A monitoring program to measure the settlement at the crest of the spoil indicated an average to below average rate of settlement compared to other stable spoils at the Fording River Operations (Campbell, 1986).

A monitoring program was instituted, with a primary objective of testing the flow capacity of the coarse rock which accumulated in the base region of the dump (Nichols, 1982). Water quality monitoring has been carried out since 1982 to quantify the effects of the rock drain on the water quality of Swift Creek. It was found that the level of nitrogen in the form of nitrite remained below the acceptable concentration specified by the British Columbia Ministry of Environment and Parks. Except for initially elevated sulphates, conductivity, alkalinity, hardness and dissolved solids due to the flushing-out of the rock drain, the effect of the rock drain on these parameters was negligible.

Regular monitoring is being conducted to ensure that there is no build-up of bed-material load inside and upstream of the rock drain outlet, which could reduce the void space and affect the discharge capacity of the drain in the long-term.

6.3.2 Skyline Coal Mine, Scofield, Utah

Culverts were used to temporarily convey the stream flow while the mine was operating (Hamm, 1986). These were located in the original stream channels. It was observed that the North Fork tributary, which was one of the tributaries that temporarily conveyed the stream flow while the mine was operating, had its inlet clogged several times following construction, by earth slides following precipitation events. To mitigate the problems, a rock drain was constructed to a depth of approximately 2.4 m (8 ft) below the surface at the mouth of the small tributary valley. This drain allowed some drainage to occur even after an earth slope covered the drain inlet.

The rock drain inlet was constructed of 20 cm (8 in.) diameter durable sandstone wrapped in a fabric filter with 5 cm (2 in.) diameter filter rock over the fabric.

6.3.3 Colowyo Coal Mine, Colorado

Excess spoil from the mine operation was hauled to a valley fill at the east edge of the mine area (Hamm, 1986). The spoil material was first deposited in a 61 m (200 ft) lift with subsequent lifts of 15 m (50 ft) each. This material was deposited by end-dumping from trucks, thereby creating a natural sorting of rock material size through the action of gravity. Coarse rock was concentrated at the bottom of the fill with decreasing rock size toward the top of each lift. This created a natural rock drain in the valley bottom. Although monitoring wells indicated a piezometric surface at depth in the fill, no outflow at the toe of the fill has been noticed.

TABLE 2
COAL MINE WASTE DUMPS
ROCK DRAIN SURVEY

DESIGN FLOOD			STREAM GRADIENT (%)	ROCK DRAIN DESIGN							MONITORING PROGRAM	COMMENTS
FLOW (m3/s)		RETURN PERIOD (YEARS)		CONSTRUCTION METHOD	ROCK FILL DESCRIPTION		DIMENSIONS (m)			DESIGN FEATURES	DEPTH OF SATURATION AT DESIGN FLOW (m)	
PEAK	MEAN DAILY				TYPE	TESTS	WIDTH	LENGTH	THICKNESS			
6.2 SMOKY RIVER COAL MINE–WASTE DUMP (HAUL ROAD)–NO. 12 MINE ACCESS ROAD–1.029 CREEK CROSSING												
21	?	200	7.5	Pre placed lift of end–dumping of selected waste rock	Sandstone Siltstone	Slake–durability, unconfined compression test Slake–durability, unconfined compression test	35	150	3	Pre constructed outer core stone diameter=0.3m End dumped inner core stone dia.=0.9–1.5m.Top lift of random waste		– Water quality – Inlet water levels – Inflow and Outflow – Aquatic biota study downstream of drain	–Rock drain performance is satisfactory to date
6.3 CROWS NEST RESOURCES LTD.–LINE CREEK MINE												
6.3a LINE CREEK DUMP												
64	37.5	200	3.0	End–dumping of the selected waste rock	Coarse Sandstone	Point load compression tests Gradation	>150	1000	~7–10	Min. diameter =600mm	5–8	– Inlet pond levels – Inflow and Outflow – Dye tests for through–flow velocity – Water quality – Sediment surveys	–Construction to start in mid 1989
6.3b WEST LINE CREEK DUMP												
25	15	200	8.7–14.1	End–dumping	Sandstone Siltstone	Gradation	>50	2500	>3	Mean size >300mm		– Water quality – Dye tests – Outflow	–1 in 7 year flood flow measured at 1.1m3/s –Rock drain performing satisfactorily
6.3c NO NAME CREEK												
17	10	200	6.0	End–dumping select sandstone	Sandstone Siltstone	Visual Inspection	>50	1000	min 5	30m wide zone of select sandstone	5–8	– Inflow – Dye tests	–Satisfactory performance
6.4 BYRON CREEK COLLIERIES–EAST WASTE DUMP												
17	8.8	200	5.0	End–dumping of selected waste rock	Mainly sandstone	Point load compression test	100	200	~7	Median rock size: Bottom zone–400mm Upper zone–150mm	~3	– Inflow and Outflow – Water quality – Water levels in downstream toe of slope – Depth of ponding at inlet	–250,000m3 of select rock used in lower portion of dump –Construction to start mid 1989
6.5 WESTAR MINING LTD.–GREENHILLS OPERATIONS												
6.5a PORTER CREEK WASTE DUMP												
	2.95	200	10.5	End–dumping of random rock	10% sandstone 20% fiable mudstone and carbonaceous material 70% variable quality siltstone	Slake durability	~50	1800	1–2	300–500mm diameter	1–2m	– Visual inspections – Collection of dumping records – Utilization of simple crest deformation equipment – Water quality	–satisfactory performance
6.5b NORTH (CATARACT CREEK) WASTE DUMP													
		200	8.7(bottom) 26.8(top)				~50	2200	1–2				–satisfactory performance
6.6 BULLMOOSE COAL MINE–Y CREEK ROCK DRAIN												
26	?	200	7.0	End–dumping of select rock	40% sandstone 40% siltstone 20% mudstone/ shale	Point load index tests Slake durability tests Magnesium sulphate soundness tests	>20	2500	>20	Average rock size=300mm	4	– Dye test – Inflow and outflow – Water quality	–Filter cloth used above pre placed rock drain –Flattening toe berm at toe of dump eliminated based on observed performance –Piezometer monitoring across drain –Satisfactory performance
6.7 GREGG RIVER RESOURCES LTD. – BERRY'S CREEK ROCK DRAIN												
48	24.4	100	3.2	Pre placed select rock core zone; End dumped select rock	sandstone	Unconfined compression test Slake stability	100	190	12	Average rock size=600mm Overflow culvert (1200mm ⌀)	12	– Inflow and outflow rates and water quality – Aquatic biota study upstream and downstream of drain	–Generally satisfactory performance
6.8 FORDING COAL LIMITED–SWIFT CREEK DUMP												
5.8 7.1(7)		200 1000	5.2	Pre placed select sandstone Remainder was end dumped	Sandstone	LA abrasion Slake durability Magnesium sulphate soundness	pre placed drain 12.2	180	4.6	Pre placed rock drain for overflow dia.=0.6–1.0 5:1 rock fill at D/S toe	4.6	–Tests to measure the flow capacity of the coarse rock in the base region of the dump. –Tests to measure the settlement at the crest of the spoil. –Water quality monitoring. –Monitoring program to ensure that there is no build–up of bed–material load inside and upstream of the rock drain outlet.	–Free dumped rock drain adequate to convey all flows to date (max flow = 1.7m3/s) –No effect on suspended sediments –Negligible effect on water quality

6.3.4 Eckman Park Coal Mine, Colorado

Excess spoil was hauled to valley fill areas which were established as permanent structures (Hamm, 1986). Two fills with durable rock underdrains were constructed to accommodate excess spoil. These underdrains were constructed along the natural drainage bottom with graded filter material and durable rock drain material. The spoil was composed of sandstone with a specific gravity of 2.13 and shales with specific gravity in the range of 2.29 to 2.39. The average unit weight of the loose spoil material was approximately 2000 kg/m^3 (125 pcf), and its gradation ranged from 87.1 percent passing a 20 cm (8 in) sieve, down to 2.3 percent passing 0.074 mm (No. 200 U.S. Standard Sieve Series) sieve.

Based on the above gradation, the rock drain filter material selected ranged from 100 percent passing a 61 cm (24 in) size, to 3 percent passing a 0.074 mm (No. 200) size. The drain rock ranged form 100 percent passing a 1 m (3 ft) size to 10 percent passing a 0.5 m (1.5 ft) size.

The drain rock and filter material consisted of durable, non-slaking sandstone quarried from the site. The spoil fill was compacted in 1.2 m (4 ft) lifts, with an overall 3 horizontal: 1 vertical slope, and 9 m (30 ft) wide benches every 15 m (50 ft) in height.

6.3.5 Rockfill across North Fork of Rose Creek

This rock fill was advanced across the North Fork of Rose Creek near Faro, Yukon (location shown in Figure 6.1). It was constructed to provide access to a proposed mining area at the Curragh Resources lead-zinc mine. The roadway fill is approximately 60 m high at the point where it crosses the bottom of the North Fork valley.

The fill consisted of calcium silicate and was placed by end dumping from roadway level. Segregation of the large fragments of the waste rock during their travel down the face of the hill, and their accumulation at the toe of the advancing fill, constituted the rock drain that conducted the flows in the North Fork of Rose Creek through the base of the roadway fill.

Inspection of the North Fork rock drain in May, 1987 (Campbell, 1989), provided some information regarding the potential clogging of rock drains as a result of deposition of suspended sediments within the drain, or as a result of deposition of bedload at the inlet end of the drain. When the North Fork rock drain was inspected in May 1988, it was found that the pool on the upstream end was higher than it was at the time of the earlier inspection. Fine grained sediment had been transported and deposited on the upper surface of boulders at the inlet end of the drain. A grain size analysis of a sample of the sediment indicated that all the particles were smaller than 0.074 mm (No. 200 U.S. Standard Sieve size).

The flow velocity through the voids in the rock drain was calculated to be approximately 0.1 m/sec. The settling velocity of a 0.074 mm size particle would be approximately 3.4 mm/sec. In the case of turbulent flow, particles having a settling velocity of about 3 percent of the flow velocity would not settle within the drain and these particles would probably be swept through the rock drain with the flow (Campbell, 1989).

7. MONITORING

Once the dump design has been established, a program of hydrological and hydrogeological monitoring is established to verify the design flow capacity of the dump. Proposed methods include the following:

a) Comparison of flow rates entering and leaving the dump.
b) Measurement of flow velocities within the dump, correlated with water levels at the inlet and outlet faces.
c) Measurement of piezometric levels within the dump.

Selection of a monitoring method depends on the specific set of circumstances applicable to the dump.

Regulatory authorities have indicated concern and often requested monitoring be conducted to determine the effects of rock drains in the areas of:

* nutrient loading from explosive residue in waste rock,
* changes in drain conveyance capacity over time,
* water levels within the drain and at the outlet,
* sediment accumulation at the inlet,
* streambed degradation below the outlet,
* changes in water temperature across the rock drain, and,
* benthic invertebrate and fishery habitat downstream of drain.

The location and nature of some of the monitoring elements proposed or implemented at several coal mines in western Canada are summarized in Figure 7.1. Specific monitoring programs for the respective mines included in this study were described in Section 6. A fairly complete monitoring program would ideally consist of the following measurements:

* flow and temperature - continuously during the open water season,
* water levels - daily,
* water chemistry and suspended solids - monthly except during freshet, then weekly, and,
* flow-through velocity and sediment parameters (deposition, bed degradation, substrate quality) - annually.

Nutrient loading to streams from rock drains occurs from the leaching or washing of explosive residue from the rock within the drain and, to a lesser extent, the overlying dump material. The inorganic nitrogen load generally consists of predominantly the nitrate compounds, ammonia and nitrite-N (Ferguson and Leask, 1987). In combination with phosphorus, nitrogenous effluents can produce excessive growth of algae and cause toxicity to aquatic organisms. Other water quality parameters which may be measured for regulatory agencies include suspended solids, turbidity, pH, temperature and iron content.

Changes in drain conveyance capacity can be monitored using dye tracers to determine the water travel times through the drain at a given flow. Reductions in capacity will result in increased dye travel time at the same or similar discharge. The relationship between the water surface elevation at the rock drain inlet and the discharge through the drain can also be plotted against time to detect any increase in the hydraulic gradient needed to convey a given flow. Water levels within the drain and at the outlet also provide data on the long-term conveyance capacity. The water level at the downstream end of the drain is also important to the stability of the outlet slope.

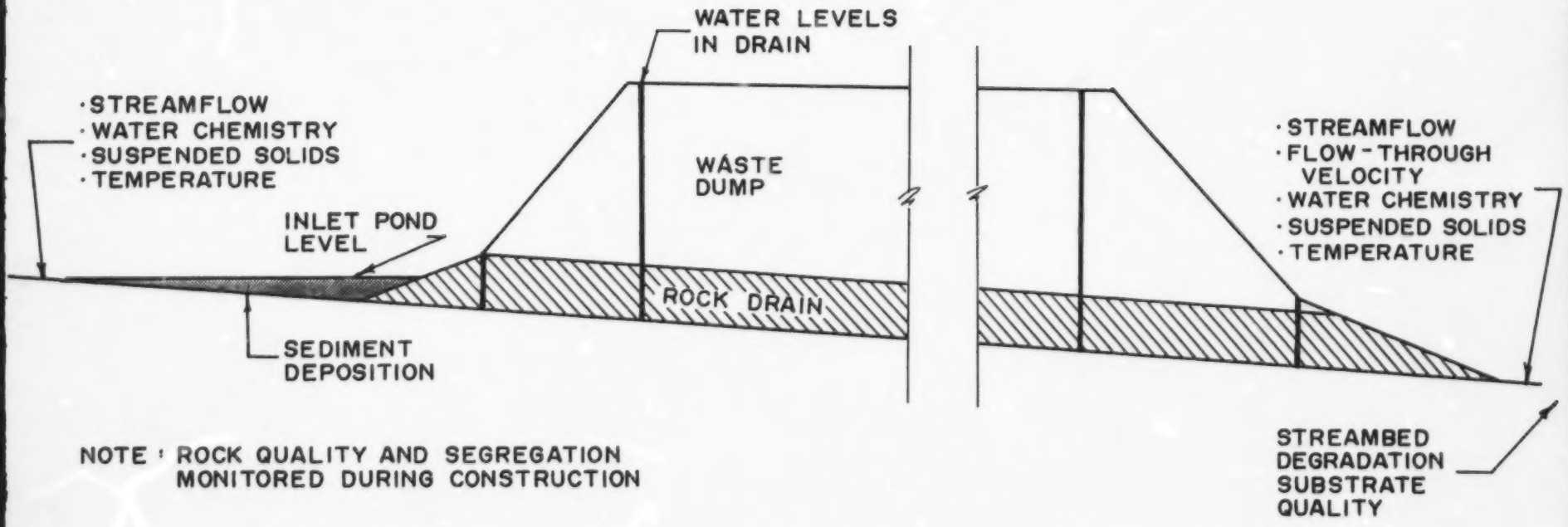
Changes in the sediment regime of the affected water course, and the retention or release of sediment by the rock drain are monitored principally by measuring the concentrations of suspended solids at the inlet and outlet. Annual samples for analysis of particle size distribution are intended to provide evidence as to the source of the suspended solids emanating from the

drain. Sediment accumulation at the inlet and streambed degradation below the rock drain outlet can be monitored by surveying the streambed annually in these locations to determine geomorphic changes.

With the increasing length of rock drains, the potential exists for a change in the temperature regime of the water course. The extent of the change caused by the relatively stable temperatures within the drain as compared to the atmosphere can be determined by the continuous measurement of inflow and outflow water temperatures. It is anticipated that the presence of a rock drain will raise downstream temperatures in the winter and depress temperatures in the summer. These changes in regime may affect aquatic fauna.

The downstream effect of rock drain construction on fish and invertebrates as a result of the changes in the sediment and temperature regime are drawing attention. The specific methods to quantify these effects have not been developed at this time.

Most mine operators realized that a waste dump - rock drain combination is a very cost effective method of waste disposal at coal mines in mountainous areas. Most operators are prepared to conduct sufficient monitoring to ensure the safe performance of the drains and to refine the design of new rock drains as monitoring data from existing structures become available.



NOTE : ROCK QUALITY AND SEGREGATION MONITORED DURING CONSTRUCTION

ROCK DRAIN MONITORING FIGURE 7.1

8. DISCUSSION

8.1 GENERAL

Rock drains provide an economical and reliable method of conveying stream flow through waste rock fills. Six mine locations in western Canada have successfully implemented rock drains in their current mine developments. In some instances, implementation of these rock drains was fundamental to the economic viability of the mine. As such, rock drains are expected to become more common and have more frequent application in the future.

The application of rock drains to surface mine waste rock disposals and stream crossings is relatively recent. Rock drain applications in western Canada were first introduced at Line Creek, in 1981. Although rock drains constructed since that time have generally included performance monitoring, the long term performance characteristics of these structures is still not clearly understood. Information gained monitoring the performance of existing rock drains may be used to refine the design methodology to be used for future rock drain applications.

8.2 CONCLUSIONS

From a review of plans of existing and proposed waste dumps in the Rocky Mountains region of western Canada, it is concluded that construction of dumps across valleys with streams is generally feasible and in the instances surveyed, can be accomplished without major impacts on stream flow and quality. In situations where the rock quality is poor, resulting in disintegration into excessive fines, consideration should be given to construction of a diversion channel, or provision of supplementary drainage at the dump bottom by means of culverts, or an artificially placed rock drain consisting of select, durable coarse rockfill.

A critical part of the dump which warrants special attention in the design is the final and intermediate slopes at the downstream end. If the downstream slopes present a concern for the protection of downstream facilities, the dump plan and construction sequence should be examined to determine whether it is possible to incorporate select, coarse rockfill into the toe.

Normally, some high-quality rockfill will be available to incorporate into either a preplaced or free dumped rock drain. The overall rockfill characteristics should be evaluated in advance to ensure that an adequate supply of coarse rock will be present to generate a drainage layer whichever dump construction method is utilized. The degree of conservatism adopted in the design depends to some extent on the likely impact that failures in intermediate and final downstream slopes would have on the down-stream environment.

8.3 RECOMMENDATIONS

In order to improve design methodology, it is recommended that a project be implemented to monitor the long term performance of existing rock drains. Specific issues which should be addressed by this project, may include the following:

* ponding potential at the inlet to the rock drain and potential plugging of the inlet;
* siltation effects within the rock drain;
* fluctuations in the water surface within the waste dump and its effect on dump stability;
* the effect of different construction methods on rock size segregation and hence on rock drain capacity;
* the effect of rock drain construction and operation on water quality;

* the consequences of overflow, particularly with regard to the stability of the downstream face of the waste dump;
* biological impacts upstream and downstream of drain;
* the lack of a standardized procedure for rock drain design, including appropriate methodologies for determining minimum rock quality and gradation, and flow-through prediction for a widely graded material.

Information gained by such a project, could be utilized to rationally include the performance of existing rock drains into a standardized procedure for designing future rock drains.

This report prepared by:
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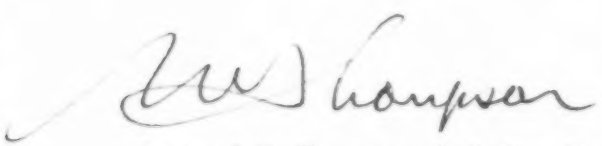
Frederic B. Claridge, M.S., P. Eng.



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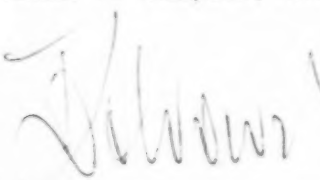

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APPENDIX I

SCOPE OF WORK

APPENDIX "A"

14SQ.23440-8-9188

STATEMENT OF WORK

The contractor will carry out in consultation with the Scientific Authority the following:

1. Conduct a literature review and a preliminary study of the problem to evaluate the scope and extent of work, develop work plans and analytical procedures to analyze the topic of rock drain.

2. Contact the participating mines and other relevant organizations through telephone or through site visit with a view to gathering information on rock drains. It would consist of a preliminary study to outline the current practises, design procedures, construction practices and observed performance of rock drains at existing mine operations.

3. Document existing methodologies used for predicting stream flows on the basis of hydrologic theory and stream flow records, along with assumptions made concerning the degree of segregation that occurs at the base of waste dumps.

4. Document monitoring procedures for determining rock drain performance and impacts of the rock drain on the downstream portion of the watershed. Of specific interest are impacts of the rock drains on flow, sediment generation and introduction of nitrogenous and acidic compounds and the problems associated with the stability of dumps.

5. Develop a common coherent approach to the topic of rock drain design, construction, monitoring and abandonment.

6. The Scientific Authority will visit the mine/laboratory test sites as and when necessary to assist the contractor in the conduct of this investigation. All travels by the contractor must have written approval of the Scientific Authority.

DEBRIEFING SESSIONS:

After submission and acceptance of the final report, the contractor shall prepare a verbal presentation outlining the problems and successes associated with the work and present this material in a one day debriefing session to CANMET representatives and interested outside parties. The time and location (usually Edmonton) of the presentation will be at the discretion of the Scientific Authority who may, also, decide that the work does not warrant presentation. Costs associated with the debriefing in Edmonton, Alberta are expected to be included in the cost.